Field Monitoring for Fluvial Sediment

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U.S. Geological Survey

Rhinelander, WI and Middleton, WI

USACE sediment training 23-34 Feb 2010

(Nolan and others, 2005)

Why measure sediment?

- Models need good input, calibration, and verification data
- Management actions need supportable, reliable and reproducible data
- Evaluate the success of land conservation or stream stabilization efforts

Photo by WI DNR, 2009, Pleasant Valley watershed

Uses for sediment monitoring data

- Nutrient/contaminant loading, transport, fate
- Navigation/dredging
- Dam removal
- Clean sediment total maximum daily loads (TMDL)
- Habitat impacts
- Long-term flood risks related to sedimentation
- Reservoir storage and lifespan
- Effects of land slides, debris flows, volcanic eruptions
- Restoration design
- Model calibration

Monitoring/measurement design

- Very important to establish goals before sampling
- What are the field and analytical requirements that are needed for adequate quantification?
- Are they cost-effective?
- Need to quantify accuracy and reliability
- What time period is required?
- Need to apply the best science and methods to each situation

Field monitoring for fluvial sediment

Variety of techniques over different spatial and temporal scales:

- Flux of sediment past a particular point (Eulerian) most common method of measuring sediment loads
- Lagrangian particle tracking (following individual particles along their flow trajectories)
- Measuring volumes of eroded or stored sediment

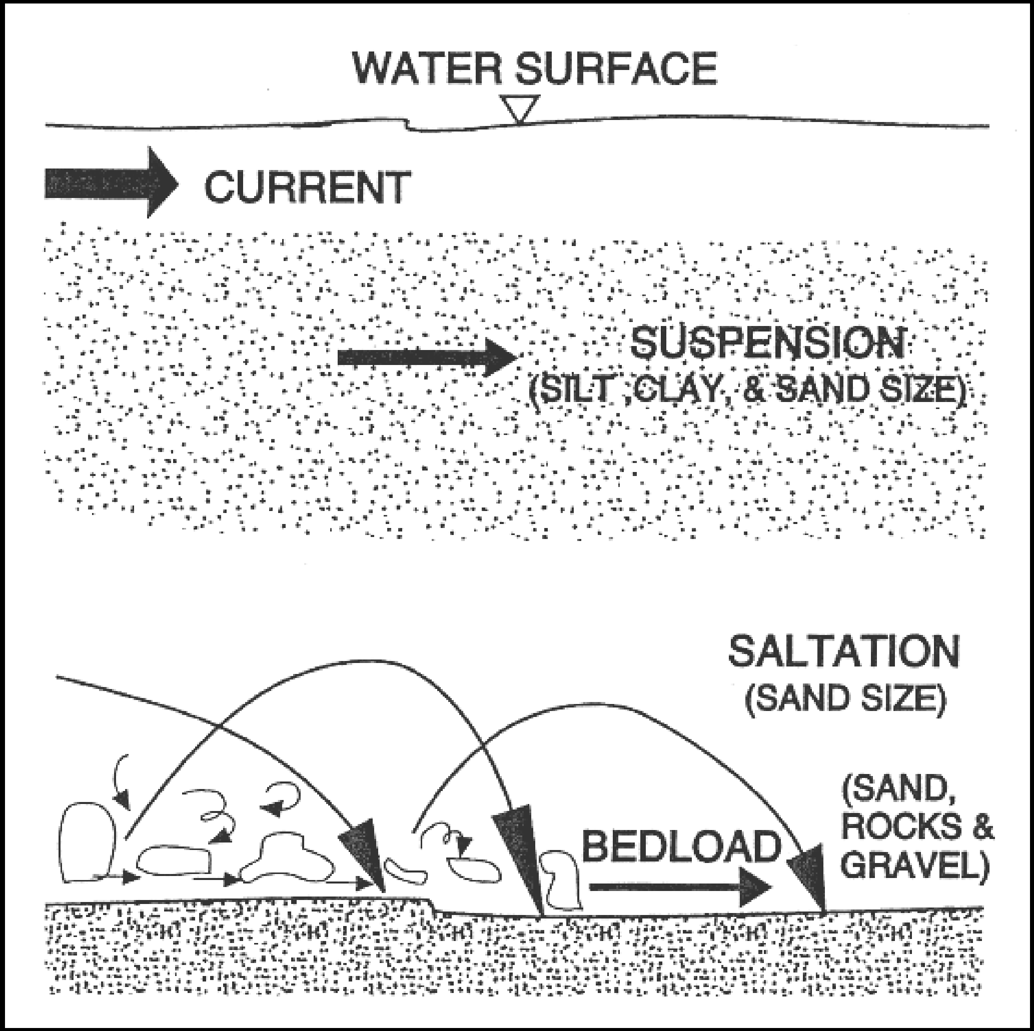
Types of sediment that can be measured/monitored

- Suspended load
- Bedload
- Stored sediment
  - bed material
  - depositional bars
  - floodplain
  - deltas

Photo by Doug Jones, White River debris flow, Mt. Rainier, Nov. 2006

Suspended sediment

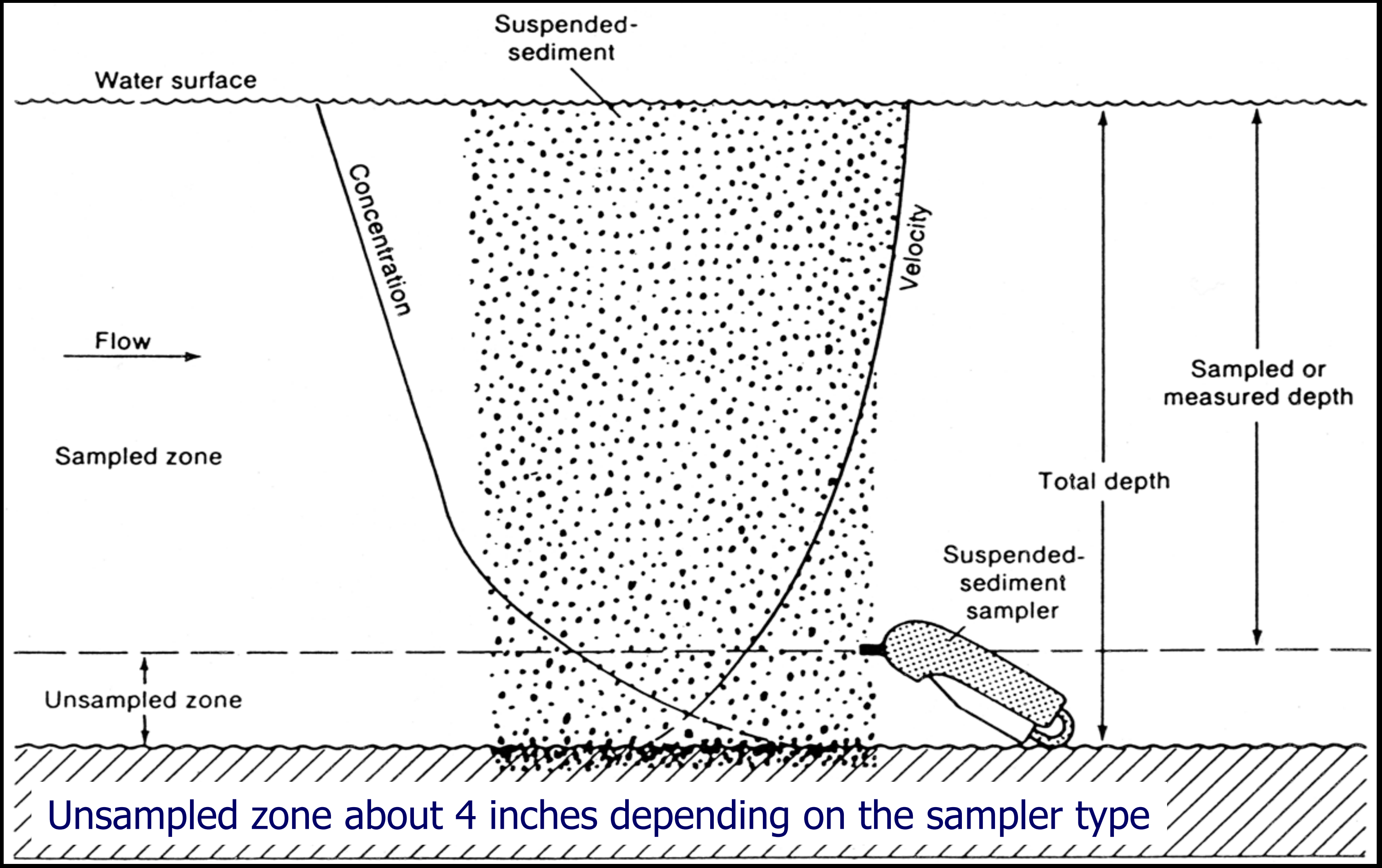
- Carried by flow in the water column
- Usually fine-grained material
- Clays, silt, fine sand, organic matter, aggregates



Bedload

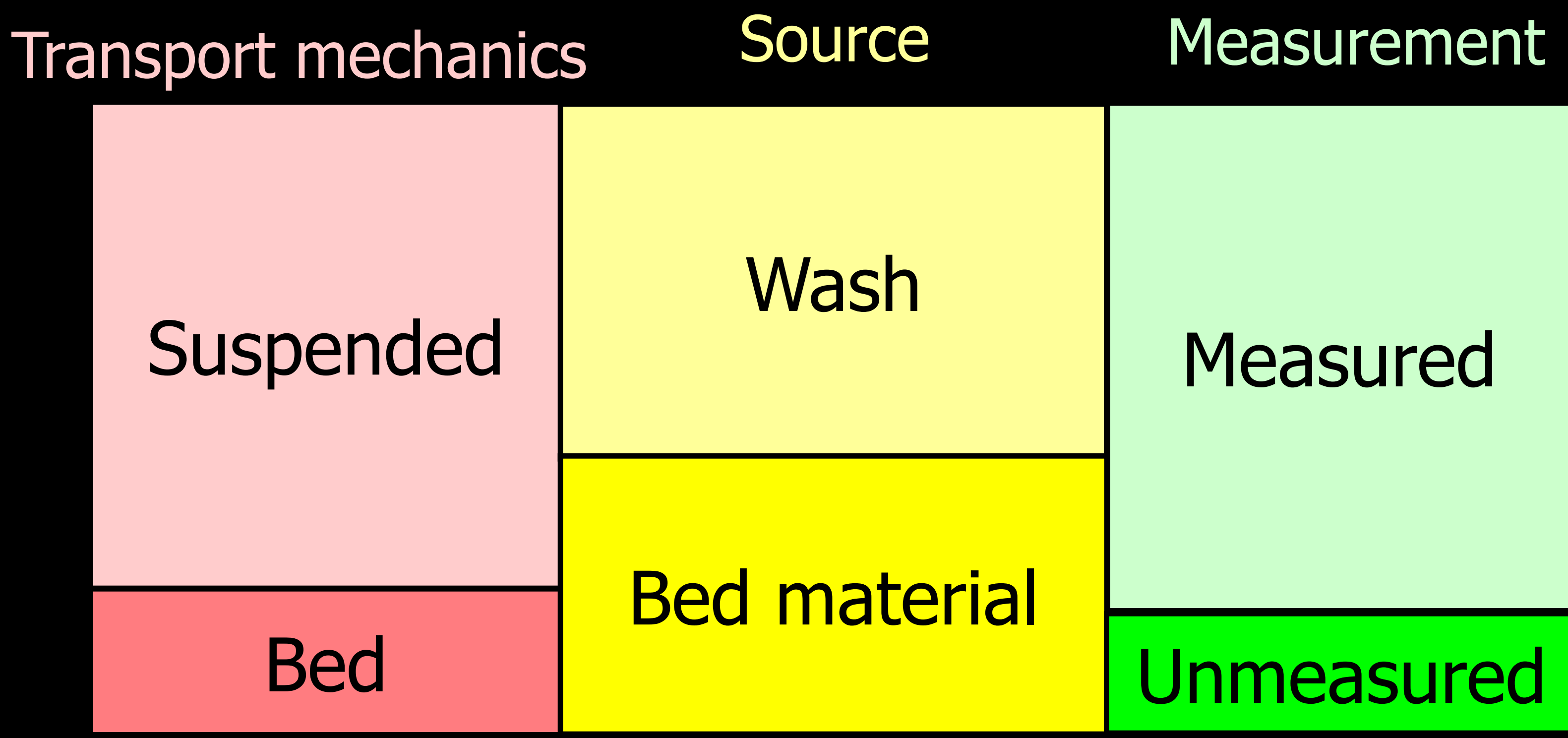
- Bounces, rolls, skips, slides along the bottom
- coarse sand, gravel, cobbles
- Hard to measure well, especially sand or mixed sizes

Sampling Suspended Sediment

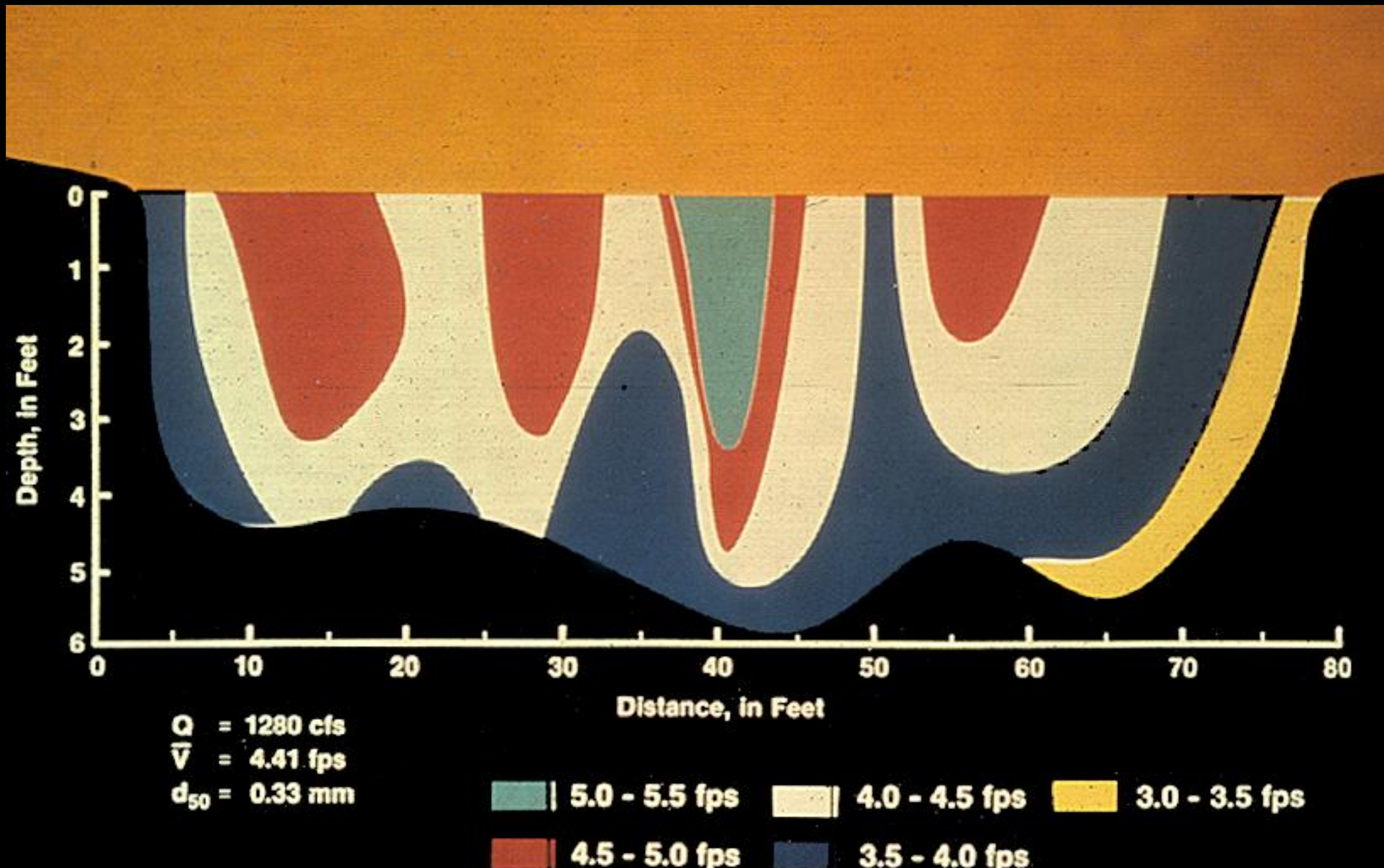


(Edwards and Glysson, 1999)

Definitions of Total Sediment Load

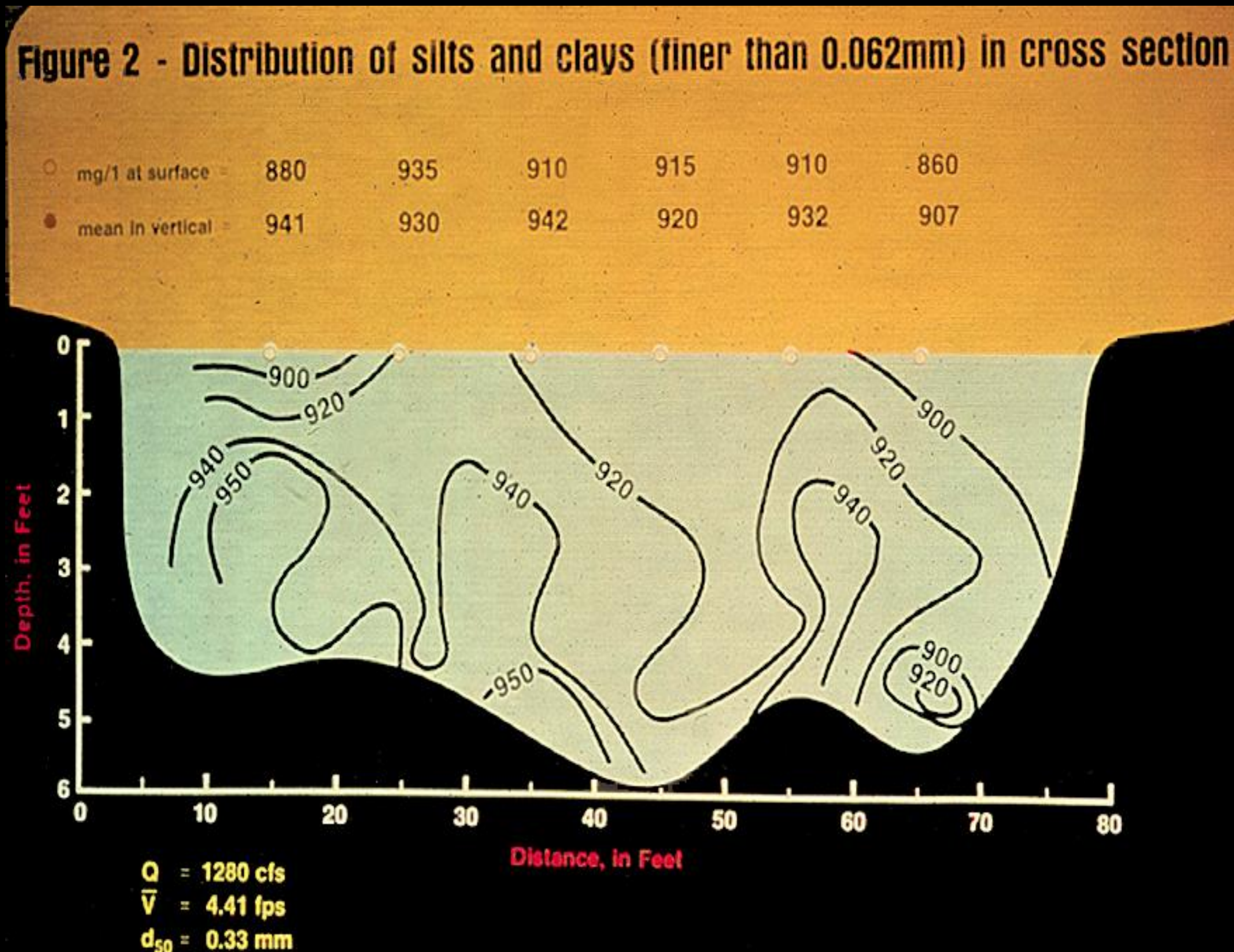


Velocity Distribution in a Channel –



Slide courtesy Larry Freeman

Silts and clays are not evenly distributed across the channel – related to variations in velocity



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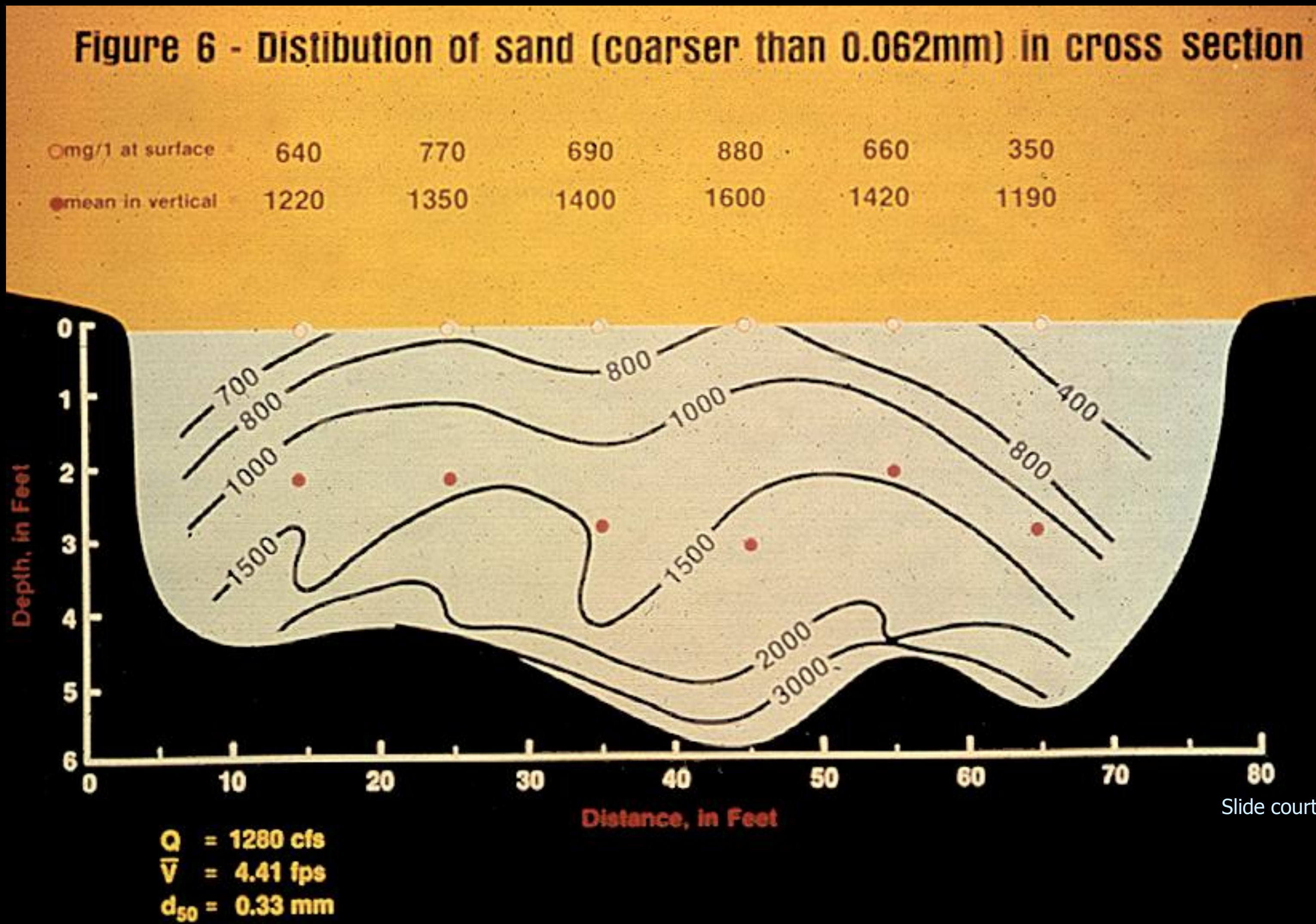
Sand distribution also variable and potentially concentrated in unsampled zone



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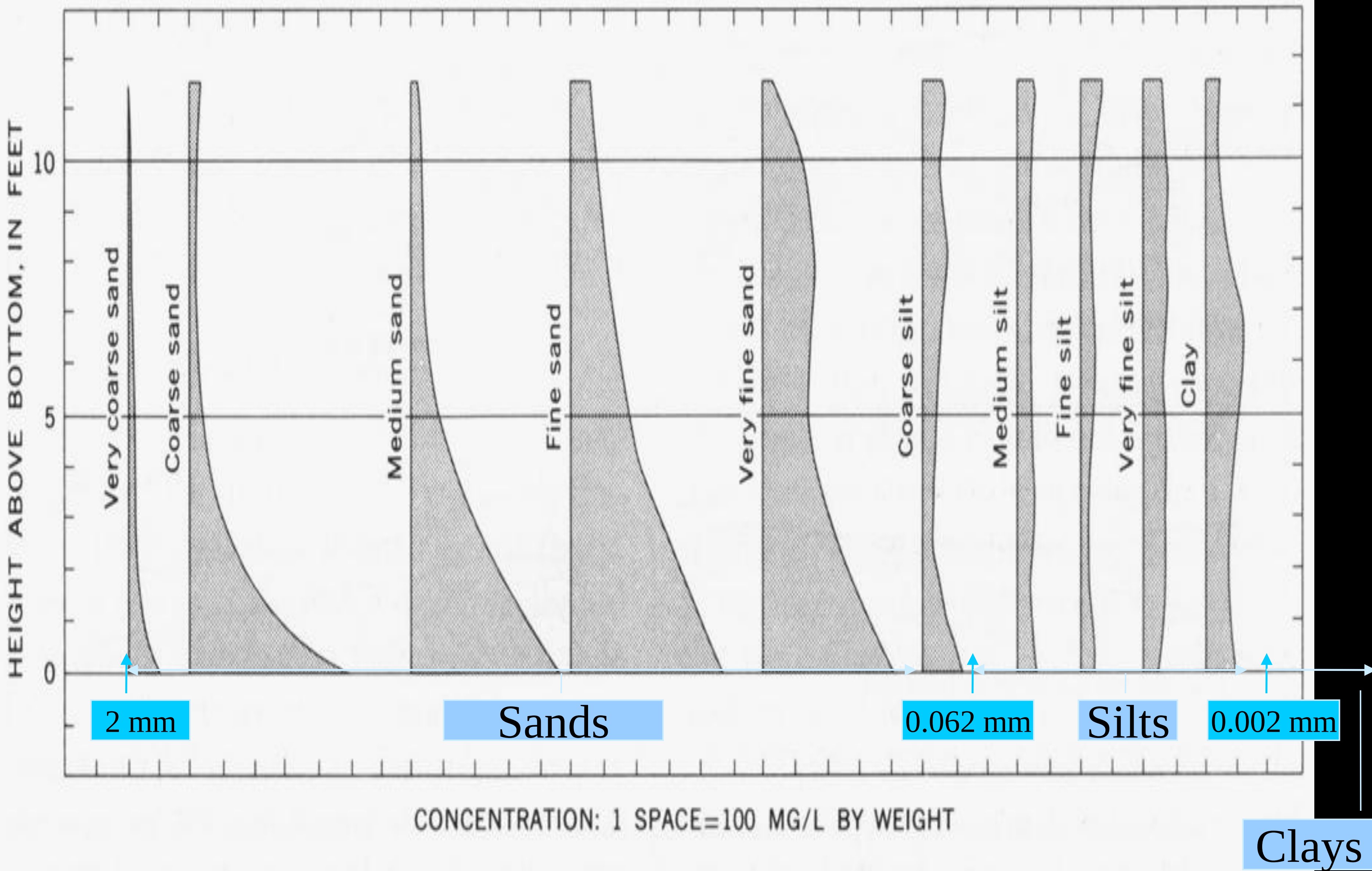
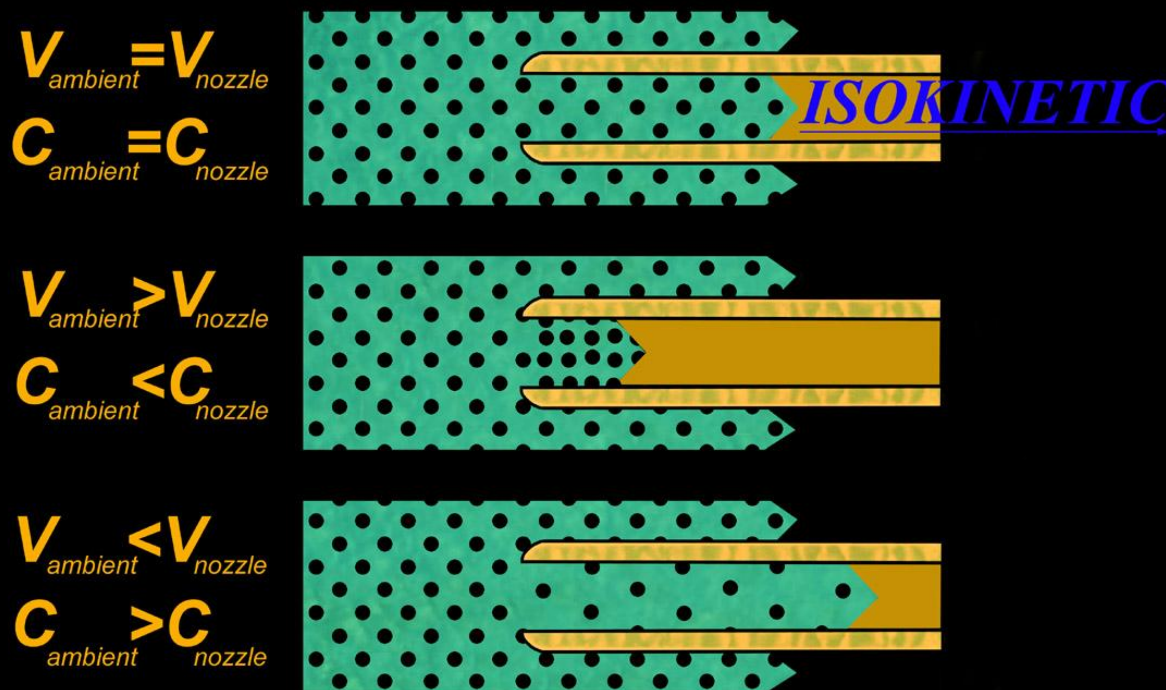


Figure 7.—Discharge-weighted concentration of suspended sediment for different particle-size groups at a sampling vertical in the Missouri River at Kansas City, Mo.

(Colby, 1963; Guy, 1970)

How do we get a representative suspended sediment sample?

#1 CRITICAL Need Isokinetic sampler = water sediment mixture moves through the intake “tube” with no change in velocity

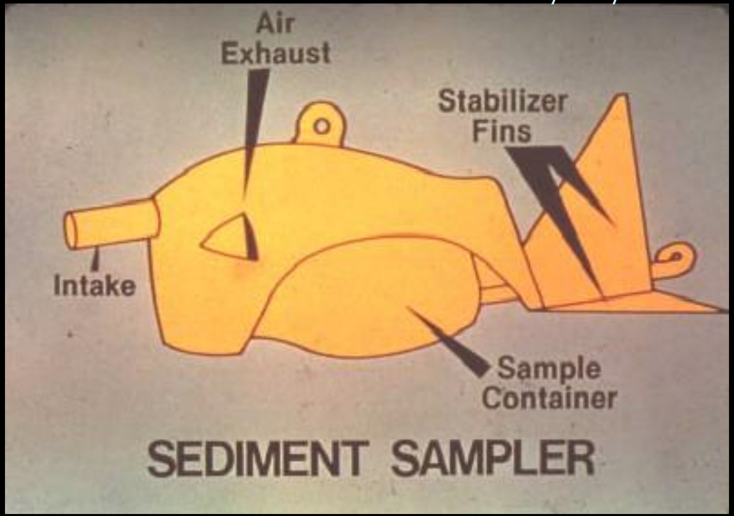


(Edwards and Glysson, 1999)

Suspended sediment sampling techniques

- Sample collection methods
  - Depth-integrated sampling
  - Point-integrated sampling
  - Point sampling
  - Grab or dip sampling
  - Pumped samples
  - Single-stage samples

Slide courtesy Larry Freeman



Depth integrating, isokinetic

Suspended sediment samplers

US P-61 –point sampler/cable

US DH-48 –wading rod

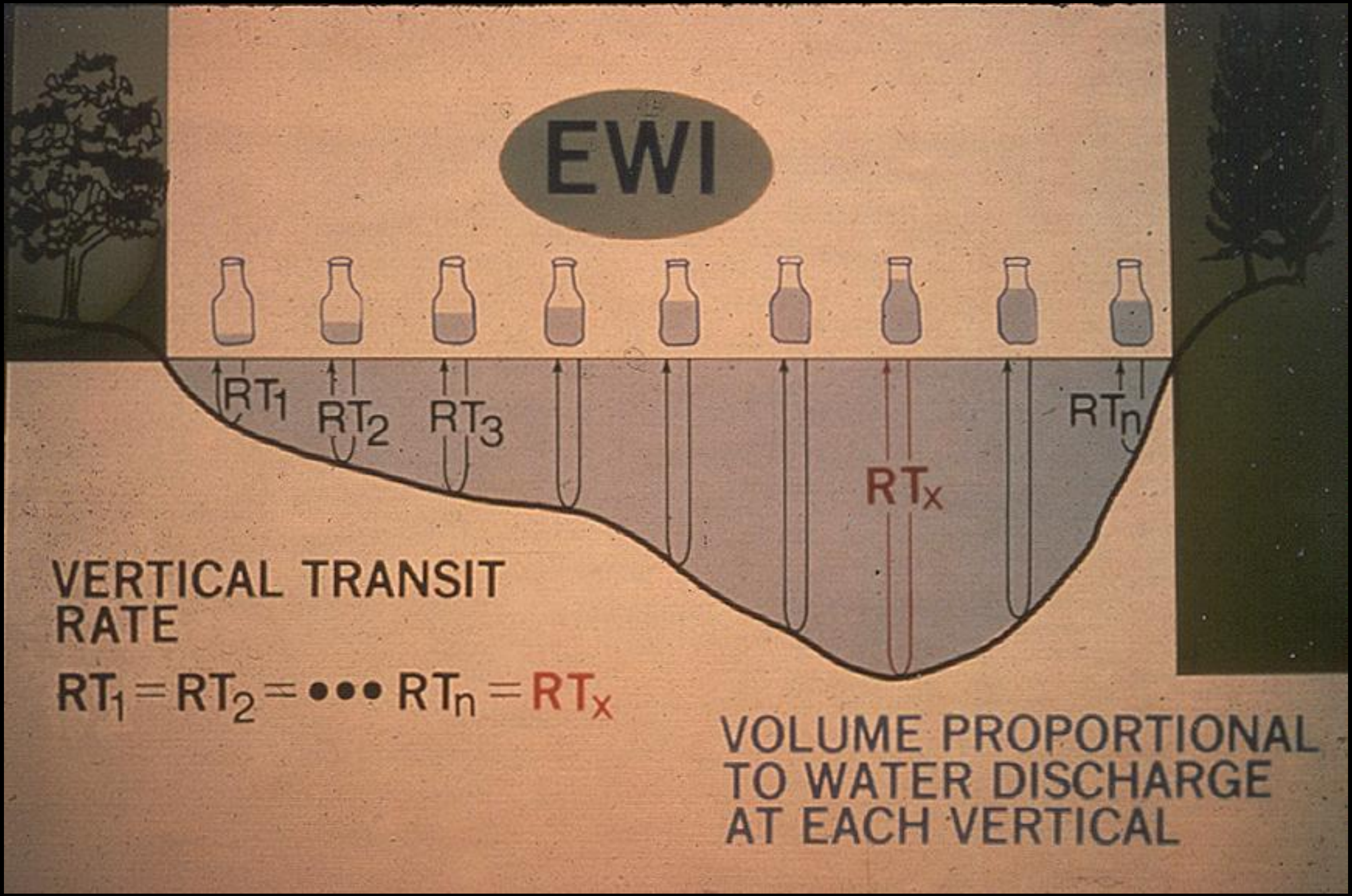
US DH-59 –cable/rope

Slides courtesy Larry Freeman

Important: specifications of suspended sediment samplers (USGS Open-File Report 2005-1087)

Sampler Designation	Nozzle ID (in)	Container Size	Max. Depth (ft)	Min. Vel. (ft/sec)	Max. Vel. (ft/sec)	Unsample d Zone (in)	Weight (lbs)
US DH-48	1/4	pint	9	1.5	8.9	3.5	4
US DH-59	¼, 3/16	pint	9, 15	1.5	5.0	4.5	22
US DH-76	3/16, 1/4	quart	15	1.5	6.6	3.2	25
US DH-81	5/16, ¼, 3/16	liter	9	1.5 2.0 ,2.0	7.0, 7.6, 6.2	4.0	1
US DH-95	5/16, ¼, 3/16	liter	15	2.1,1.7, 2.1	7.4, 7.0, 6.2	4.8	29
US DH-2	5/16, ¼, 3/16	liter	13, 20, 35	2.0	6.0	3.5	30
US D-74	¼, 3/16	pint/quart	9, 15	1.5	6.6	4.1	62
US D-74AL	¼, 3/16	pint/quart	9, 15	1.5	5.9	4.1	42
US D-95	5/16, ¼, 3/16	liter	15	1.7,1.7, 2.0	6.2, 6.7, 6.7	4.8	64
US D-96	5/16, ¼, 3/16	3 liters	39, 60, 110	2.0	12.5	4.0	132
US D-96A1	5/16, ¼, 3/16	3 liters	39, 60, 110	2.0	6.0	4.0	80
US D-99	5/16, ¼, 3/16	6 liters	78,120, 220	3.0, 3.0, 3.5	15.0	9.5	275
US P-61A1	3/16	pint/quart	180, 120	1.5	10.0	4.3	105
US P-63	3/16	pint/quart	180, 120	1.5	15.0	5.9	200
US P-72	3/16	pint/quart	72, 51	1.5	5.3	4.3	41

Equal width increment—account for variations across the channel



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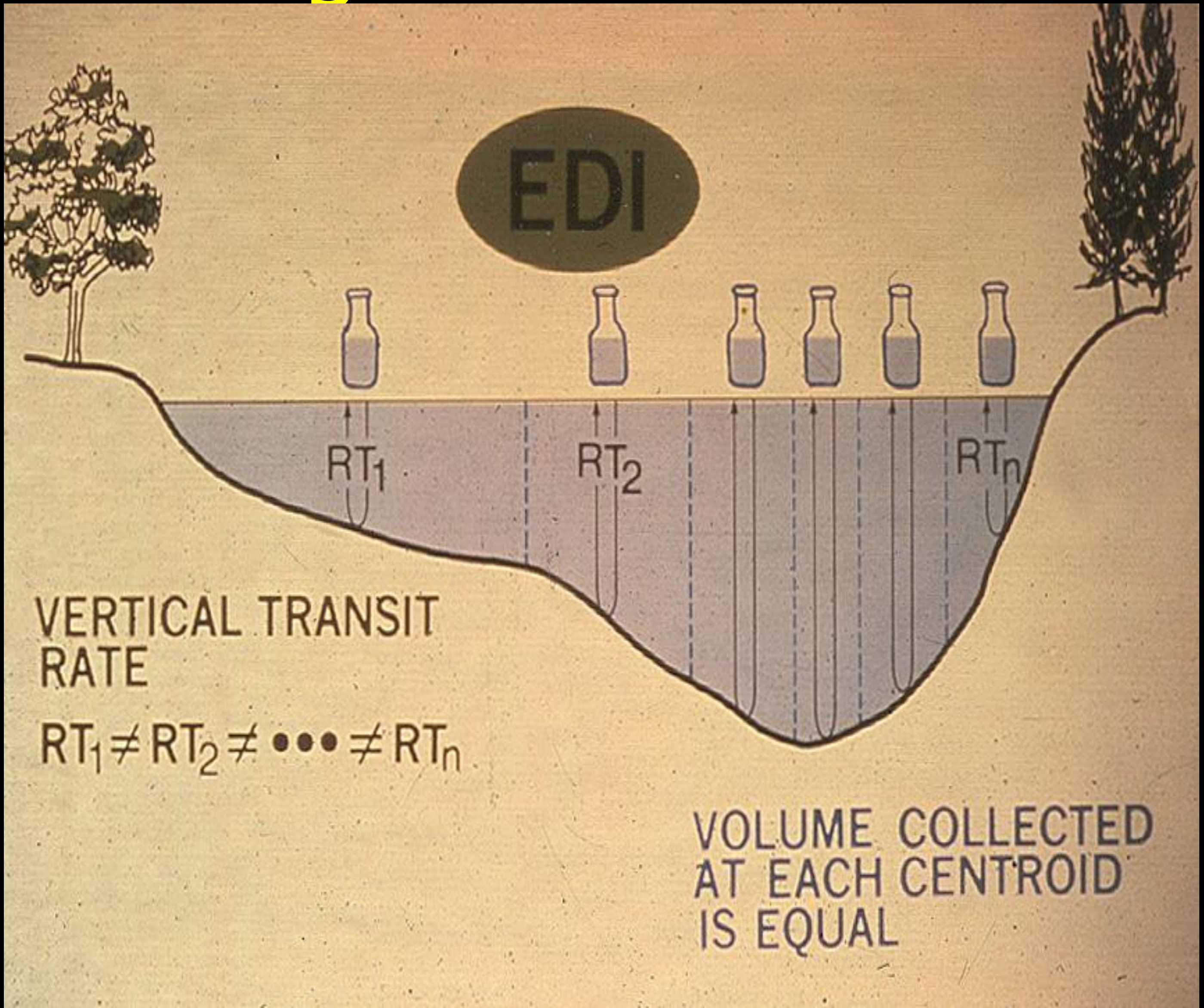
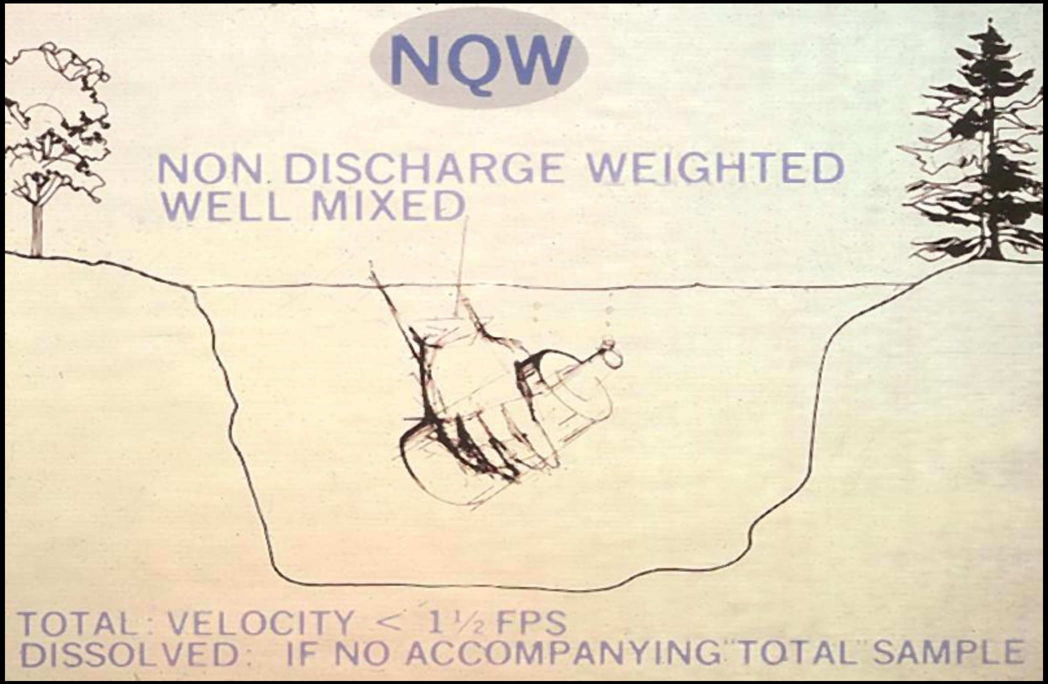
Equal Discharge Increment



Slide courtesy Larry Freeman

Grab or dip sampling

- Flow conditions or other unusual circumstances generally render standard samplers unusable
- Sediment is well mixed spatially
- Samples are not integrated
- Samples are seldom representative



(Gellis, 2007)

What would you get if you grabbed a sampled from the bank for this stream?

Photo: Eric Dantoin, North Fish Creek, 2009

Suspended sediment siphon samplers

Photo: Faith Fitzpatrick, Bark River 2006

- Remote locations with limited power capabilities
- Strengthen results if combine with stage or crest stage gage
- A few different designs
- Low Cost, easy to install

Autosampler = point sampling

- An automatic sampler, on its own, collects a volume of water/sediment mixture from a stream, lake, well, or storm drain and places it in a container for further physical, chemical, or biological analyses.

Photo: Eric Dantoin, 2009

Auto Sampler Advantages

- Samples a single point, BUT
- Sample over a storm hydrograph
- Late nights, weekends
- Need to match with a calibration curve based on cross section/depth integrated samples (flow and seasonal based)
- Critical for calculating annual loads
- Usually co-located with streamgage with instantaneous discharge

Photo: Faith Fitzpatrick, 2008

Advantages of autosamplers

- Can be pre-set to collect samples on a time, stage, discharge, volume, rainfall, and (or) in-stream surrogate basis.
- Can collect samples over the entire runoff event.
- Safer to collect samples during high flow events
- May have low labor costs
- Has the capability to be reprogrammed remotely
- Samplers can be packaged in portable units that can be easily moved from site to site

(Gellis, 2007)

Disadvantages of autosamplers

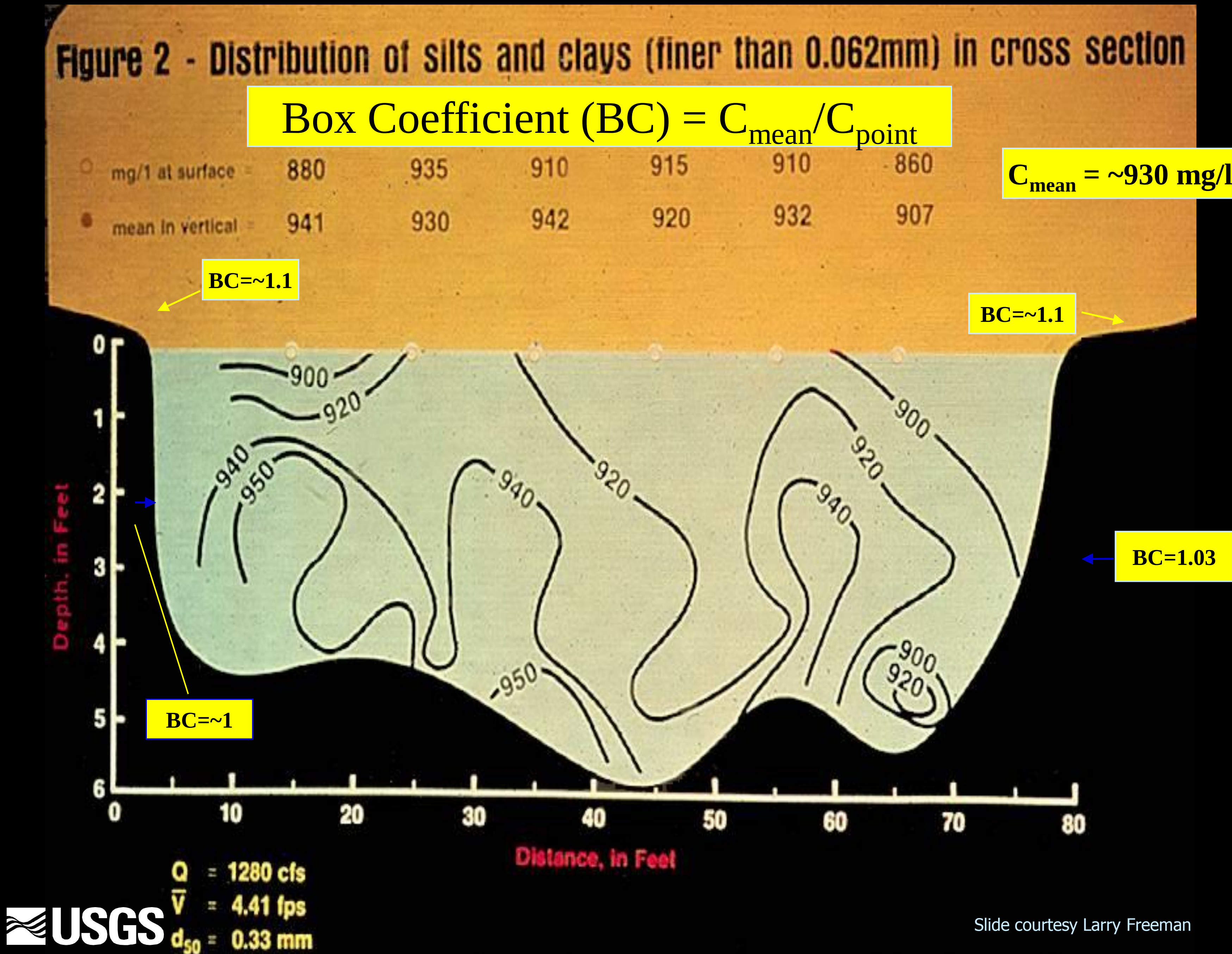
- Collects a point sample, thus requiring the samples be correlated with the “true” cross sectional mean
- Has a limited number of samples that can be collected before it must be serviced, usually 24.
- Requires power to operate
- Most pumps have a limit of about 28 feet of lift
- Sometimes high installation costs, especially if multiple sites are required

(Gellis, 2007)

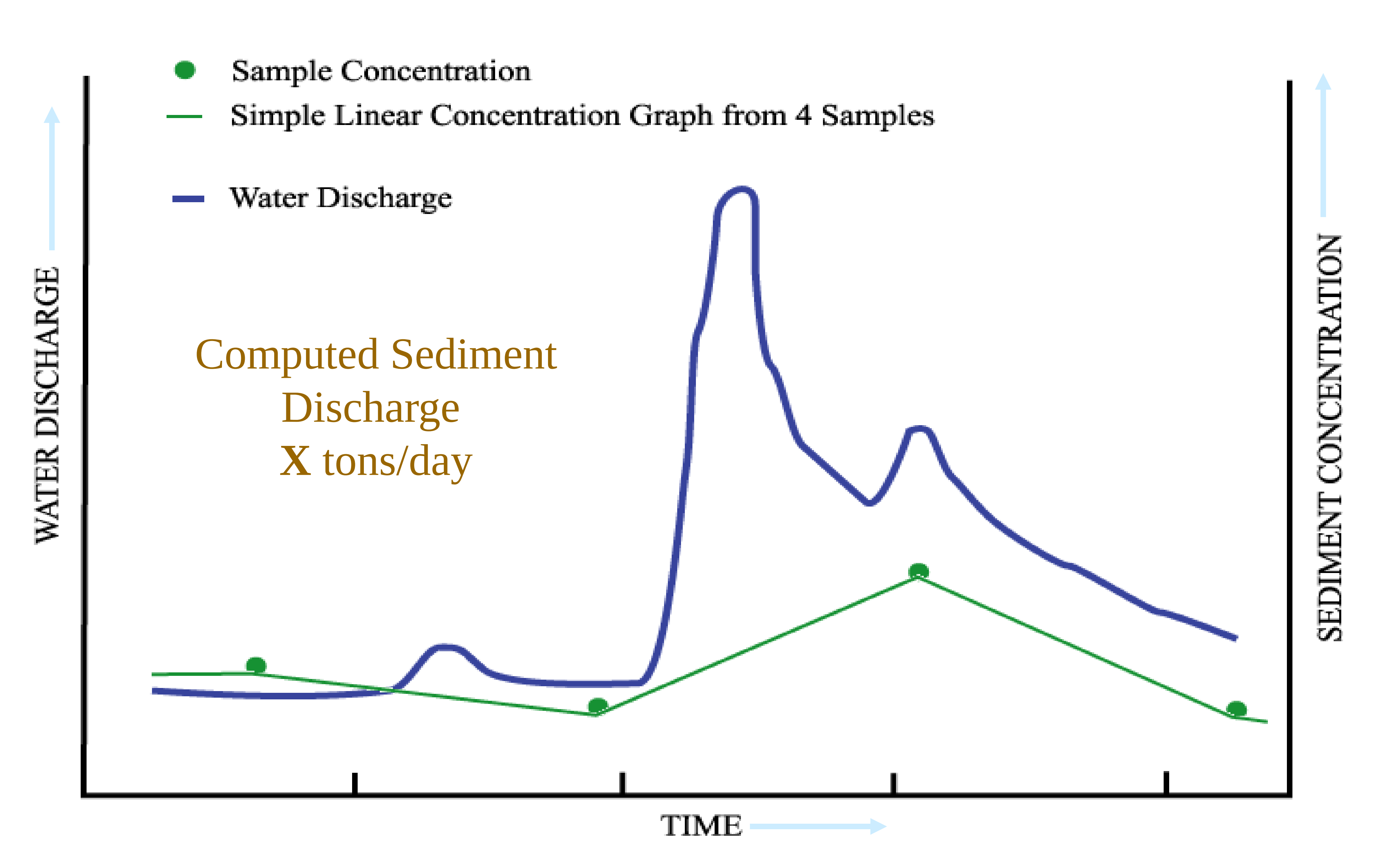
Disadvantages (continued)

- Cannot collect samples for analysis of certain parameters
- Requires maintenance of site and equipment
- Possible cross contamination if not set up properly
- Generally does not collect a sample isokinetically
- Has limits on the concentration that can be accurately sampled, especially when sand concentrations are high

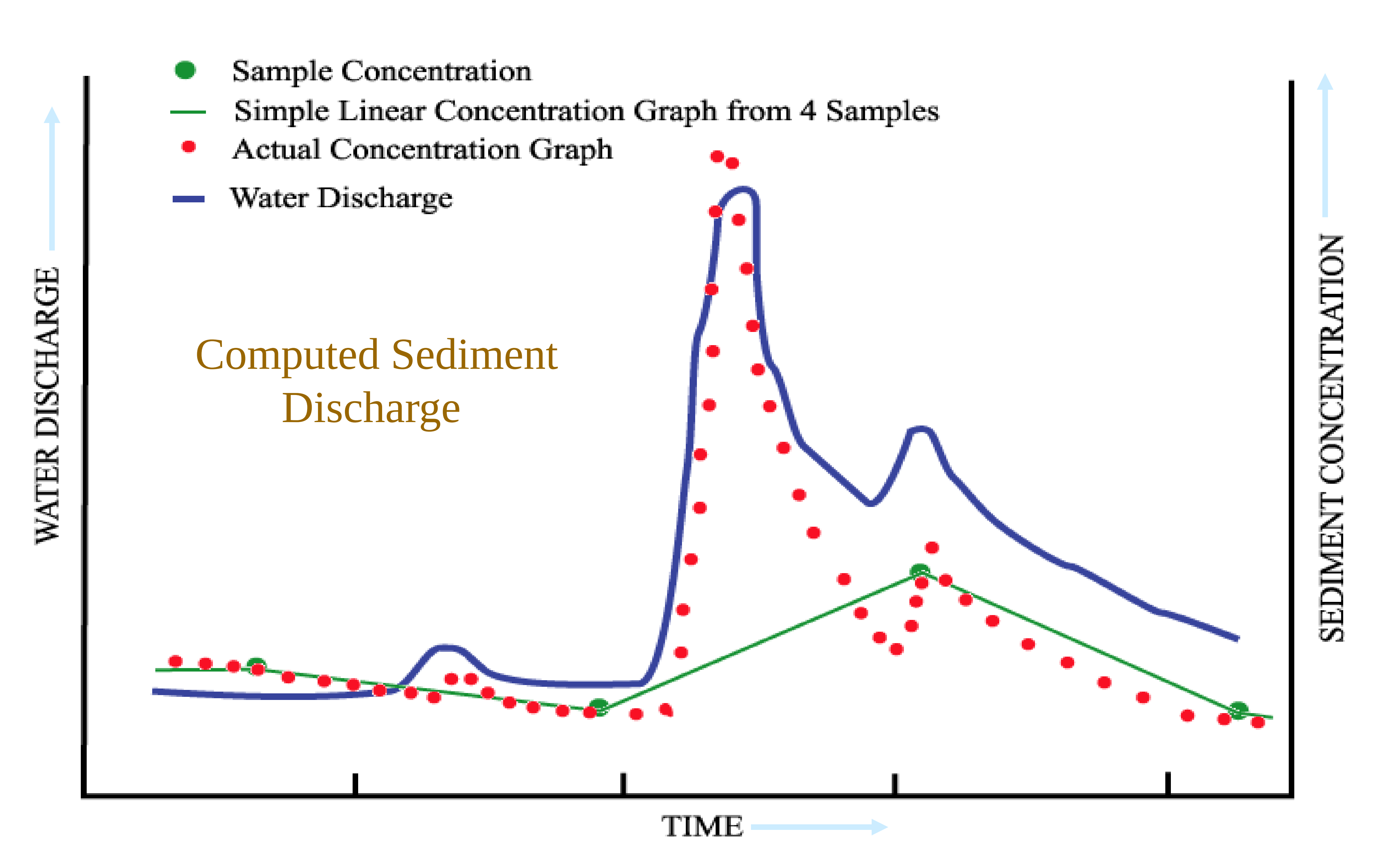
(Gellis, 2007)



Slide courtesy Larry Freeman



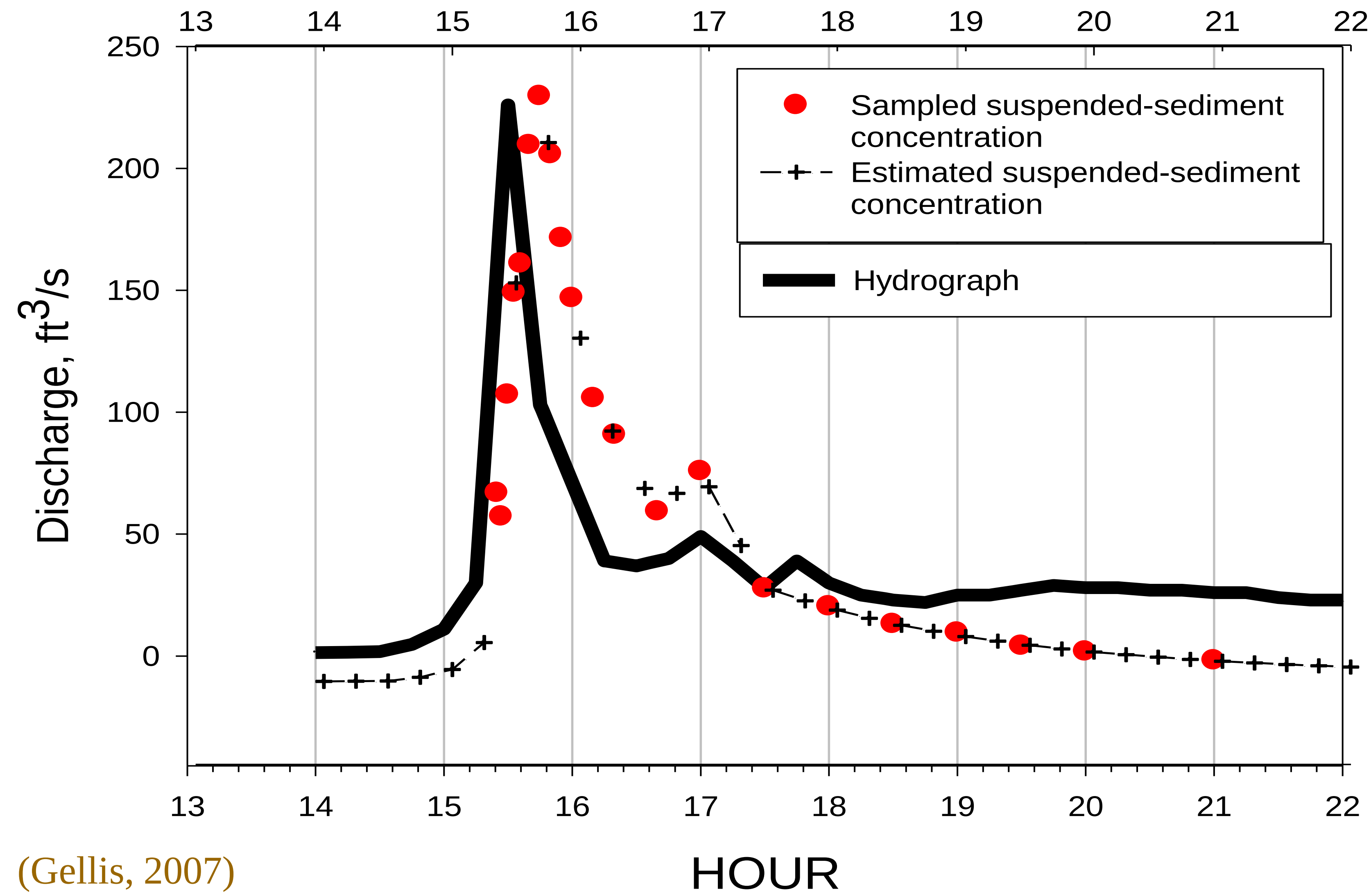
USGS (Gellis, 2007)



USGS (Gellis, 2007)

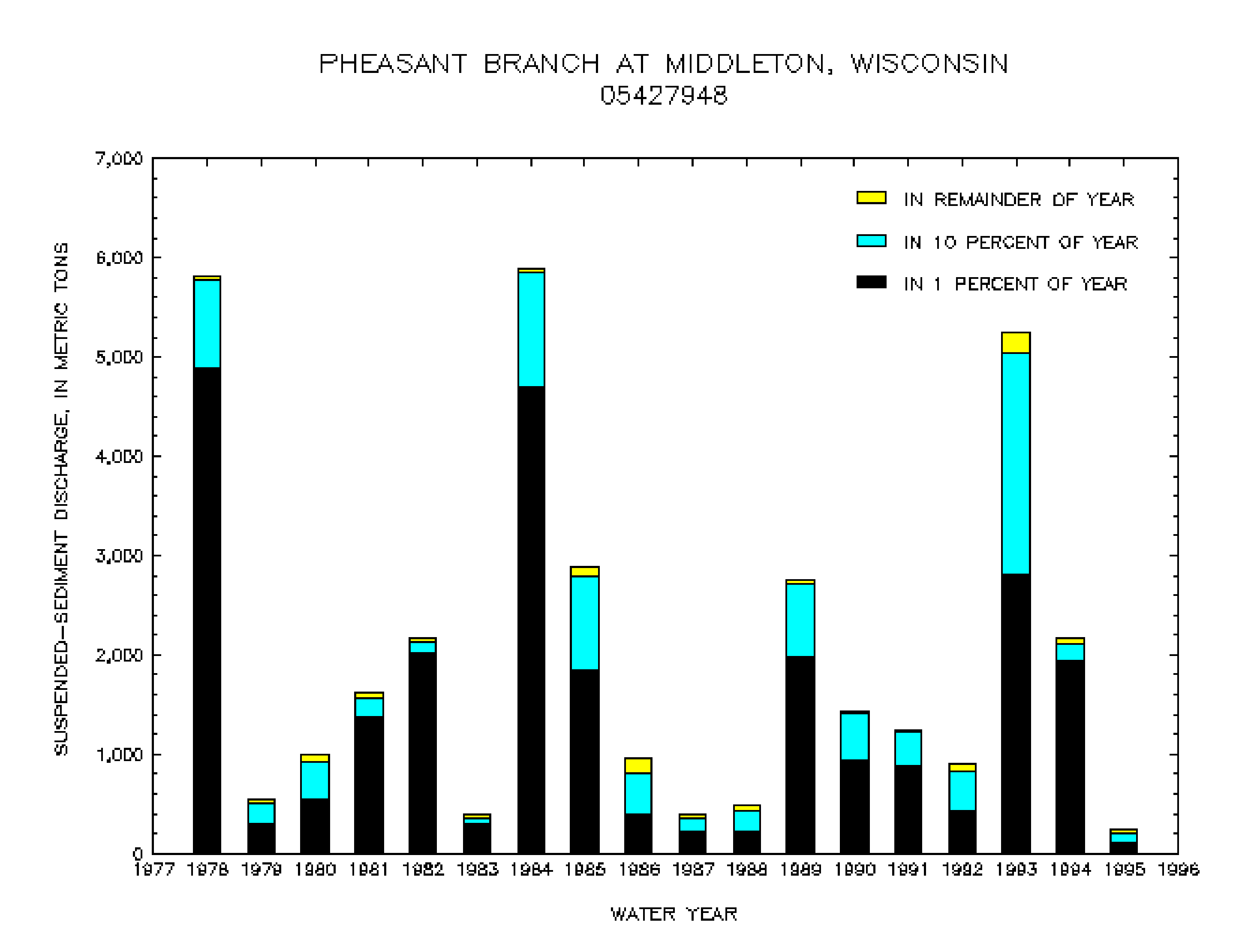
SEDIMENT SUBDIVISION

Little Conestoga Creek, PA   WY2003



(Gellis, 2007)

Importance of sampling runoff events and long-term records



http://co.water.usgs.gov/sediment

Suspended sediment surrogates

Turbidity (Optical backscatter OBS)

- Continuous sensor
- Real time data
- Site specific relation with suspended sediment
- Need to establish calibration curve – particle size, sediment composition
- Relation reaches ceiling at about 1,000 mg/L
- Turbidity standard?

Paul Buchanan (USGS), San Francisco/Delta Bay, April 1999

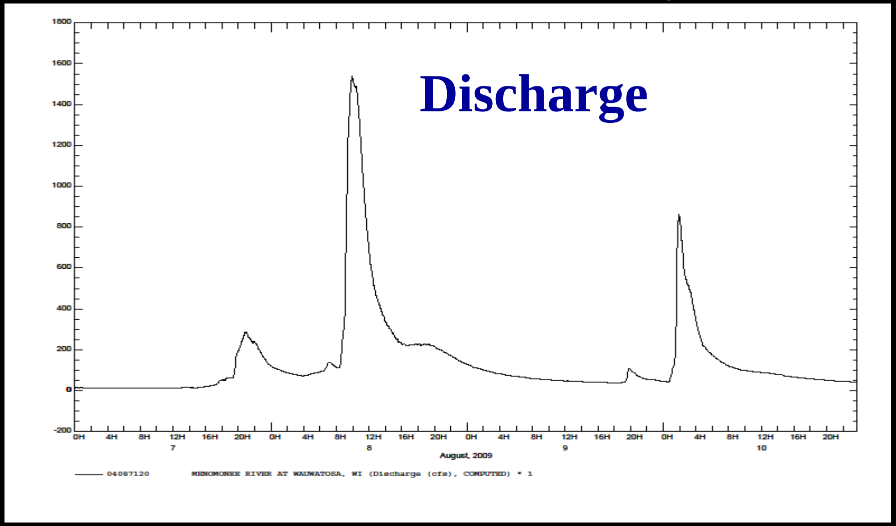
(Gellis, 2007)

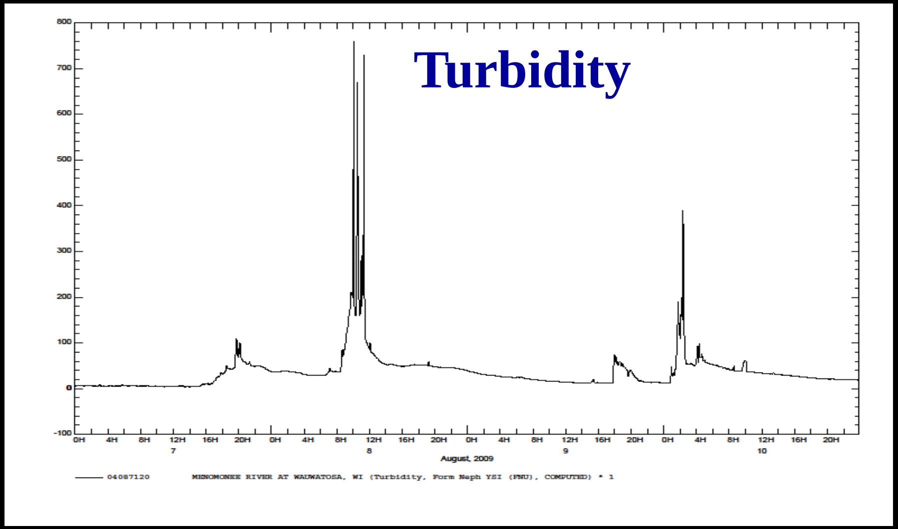
Realtime streamflow and water quality

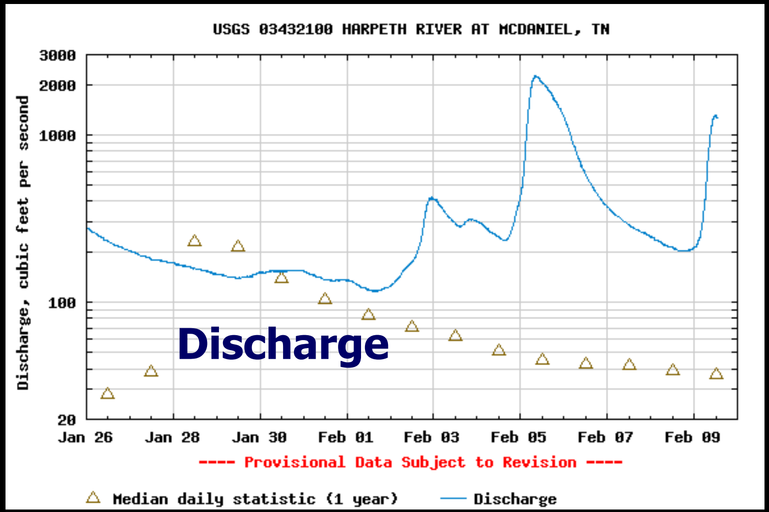
Realtime data: http://waterdata.usgs.gov/

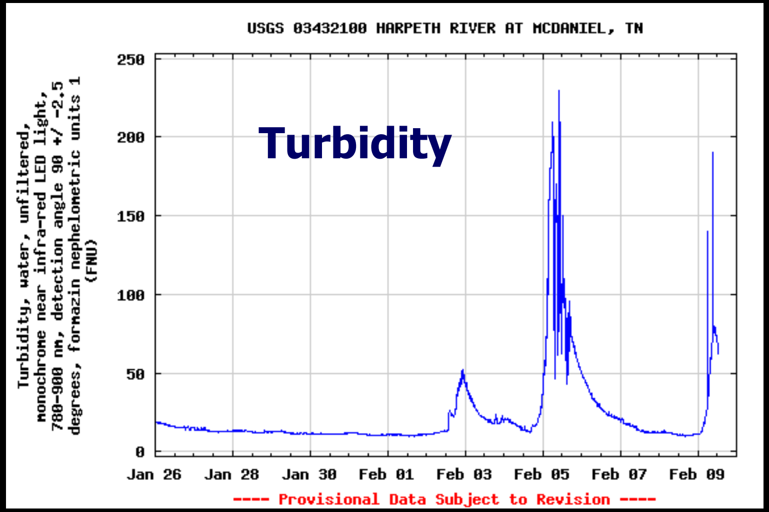
Menomonee River at Wauwatosa, WI

Harpeth River at McDaniel, TN

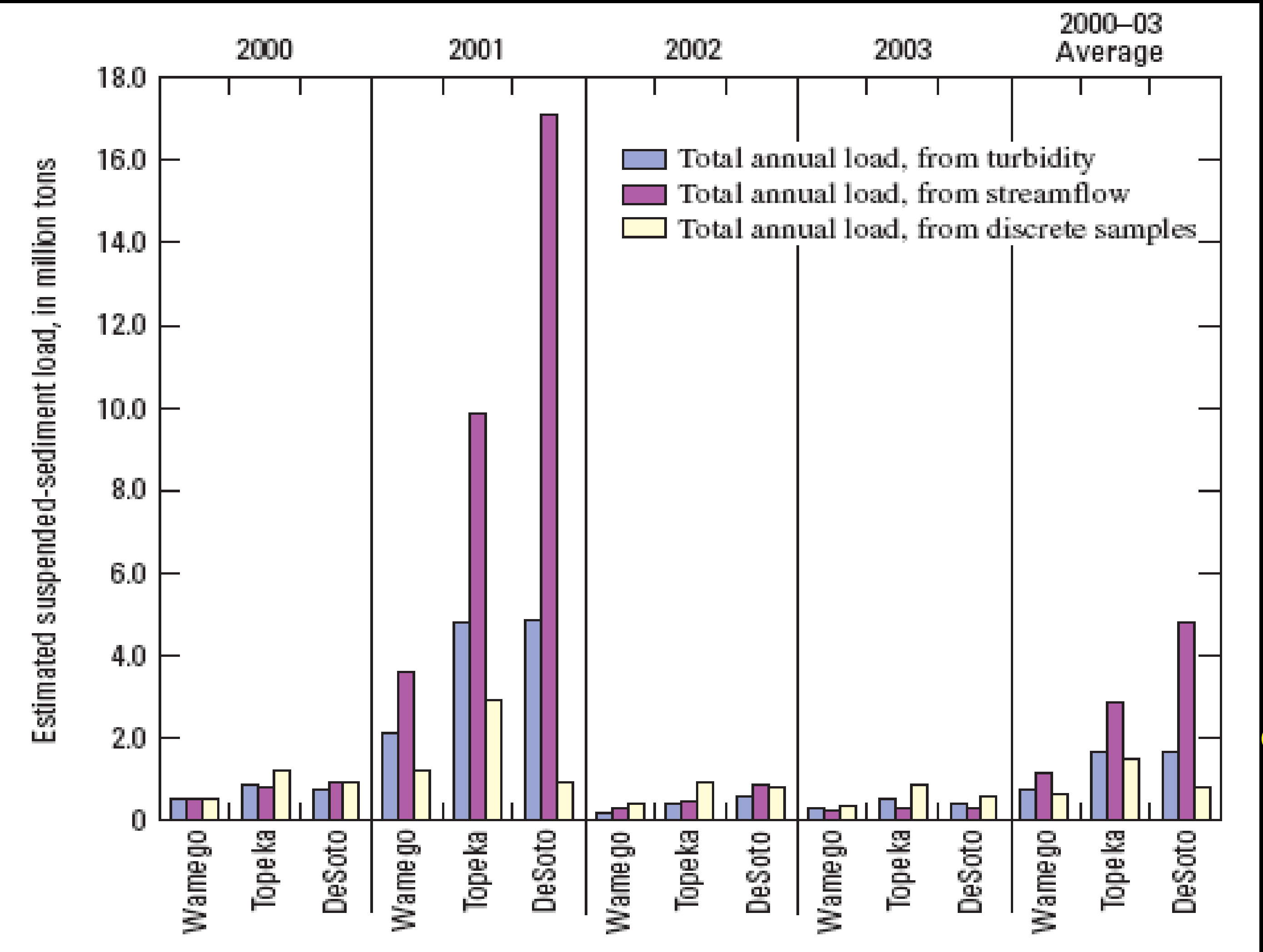








http://waterdata.usgs.gov/wi/nwis/uv/?site_no=04087120&PARAmeter_cd=00010,00011,00300,00095



(Gellis, 2007)

- Comparison of methods for annual loads of Sediment
  - A) f(Turb)
  - B) f(Q)
  - C) Discrete samples
- Error analysis shows that turbidity in realtime is best predictor

Kansas Water Science Center

USGS science for a changing world

Total suspended solids (TSS) and suspended sediment concentrations (SSC)

http://water.usgs.gov/osw/pubs/WRIR00-4191.pdf

- TSS used for regulatory purposes
- TSS and SSC = laboratory processing difference
- 3,200+ sites across the nation
- SSC more reliable than TSS
- SSC generally higher than TSS, especially for higher concentrations and more sand

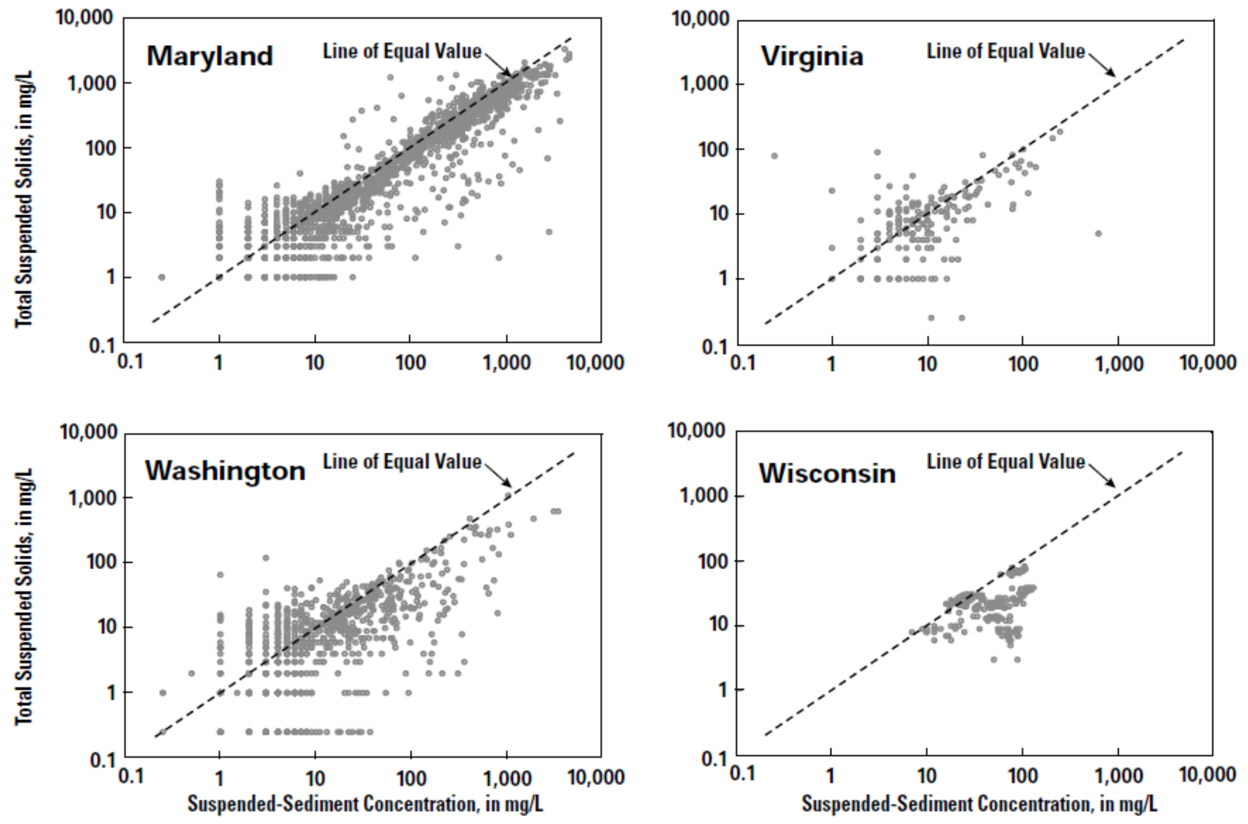
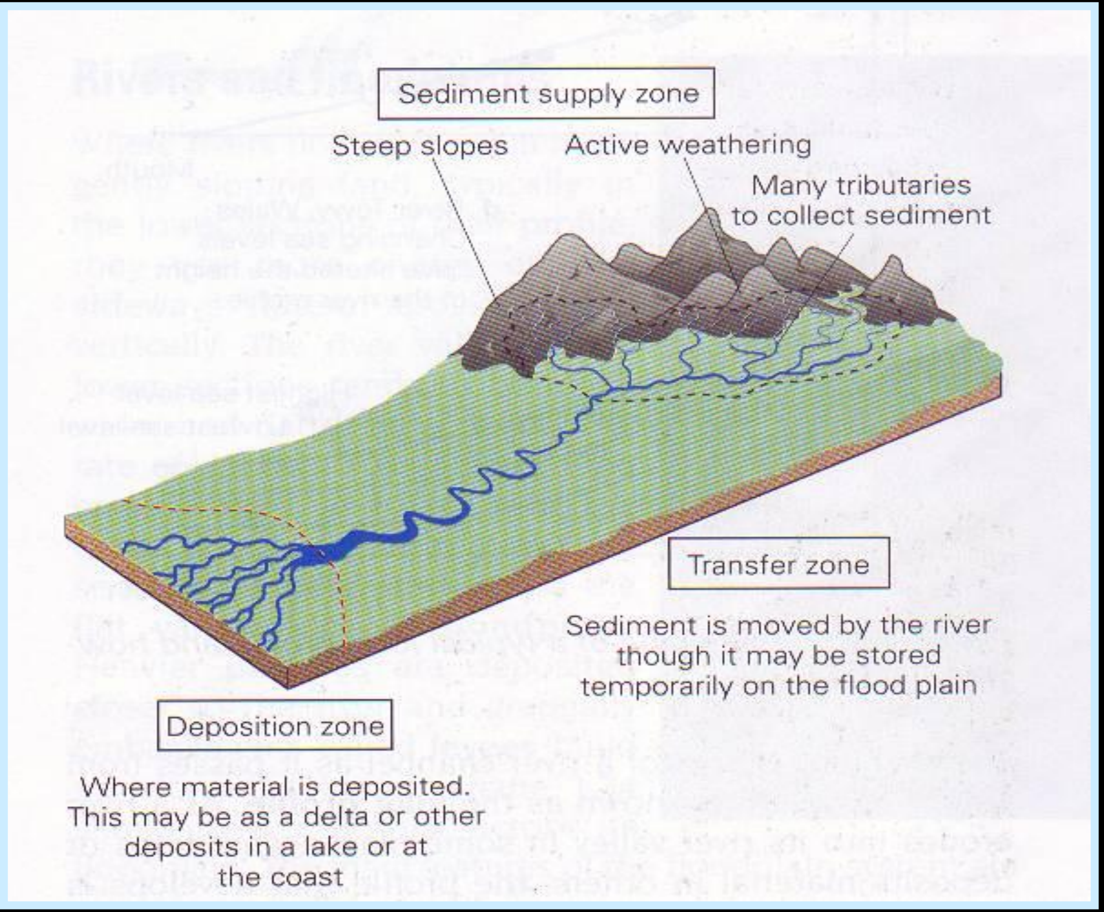


Figure 4. Relation between the base-10 logarithms of suspended-sediment concentration (SSC) and total suspended solids (TSS) for the data pairs from each State used in the analysis. All SSC and TSS values less than 0.25 mg/L were set equal to 0.25 mg/L to enable plotting the data on logarithmic coordinates.

Bedload is highly dependent on reach-scale channel and watershed characteristics

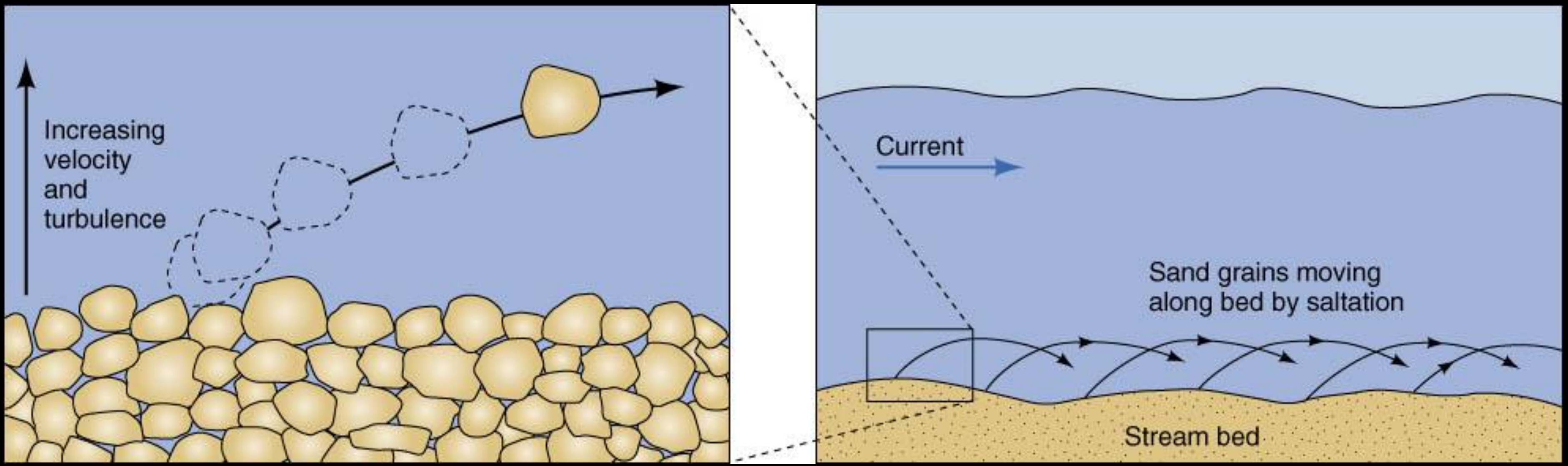
Where are you in the drainage network and sediment delivery system?

- Topography/slope
- Geology
- Slope stability
- Climate
- Soils
- Vegetation
- Water management
- Land Use



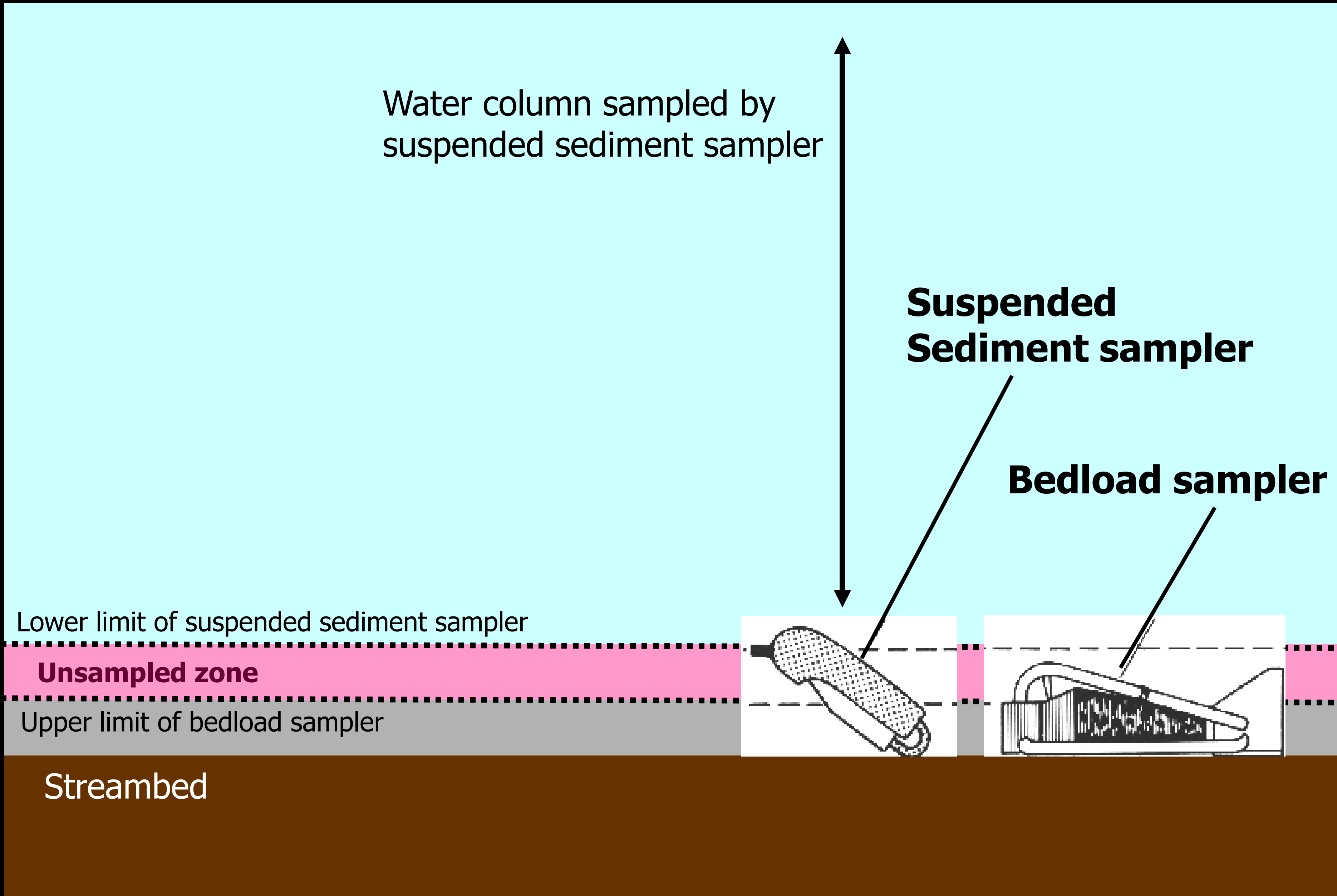
Bedload

- The bed load generally accounts for between 5 and 20 percent of the total load of a stream.
- Particles move discontinuously by rolling or sliding at a slower velocity than the stream water.
- The bed load may move short distances by saltation (series of short intermittent jumps).



Types of bedload samplers

- Box or basket
- Pan or tray
- Slot or pit
- Pressure difference

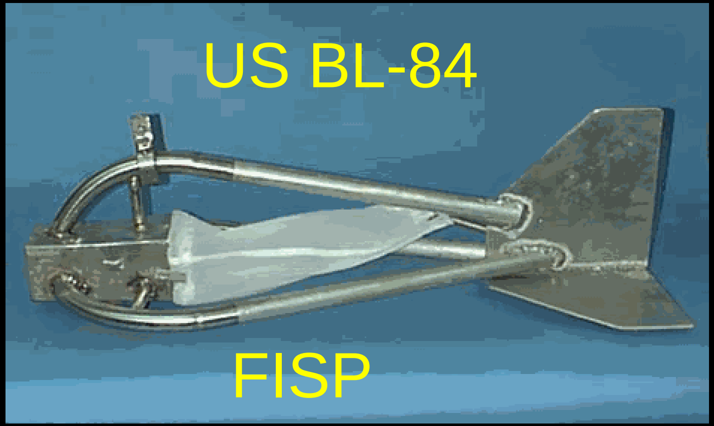


(Edwards and Glysson, 1999)

Bedload samplers

Photos: Faith Fitzpatrick

Bedload

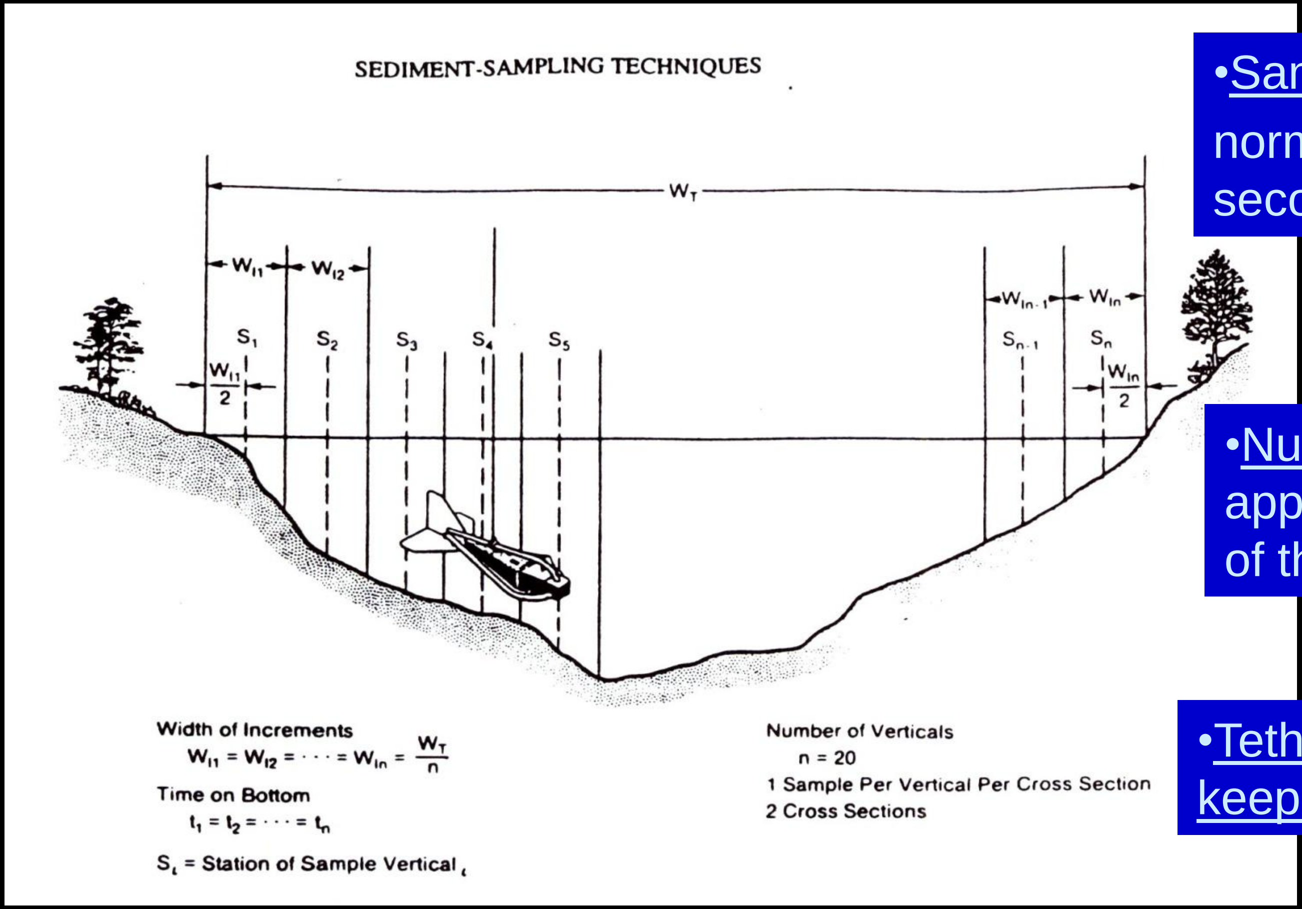


The US BL 84 was designed by the Federal Interagency Sedimentation project to collect bedload particles up to 38 mm (pebble) at mean velocities up to 9.8 feet per second. The BL-84 (ratio 1.4 nozzle expansion ratio) replaced the Helley-Smith sampler for streams with sand because the Helley-Smith sampler's nozzle expansion ratio of 3.22 caused some suctioning of sand-sized particles (oversampling).

Some pressure difference bedload samplers

Nozzle Size	Area Ratio	Type	Nozzle Thickness	Suspension	Weight
3″ by 3″	3.22	Helley-Smith	¼-inch	Cable	50-200 lb.
3″ by 3″	3.22	Helley-Smith	¼-inch	Wading Rod	
3″ by 3″	3.22	Helley-Smith	16-gage	Wading Rod	
3″ by 3″	1.40	FISP BL-84	¼-inch	Cable	35-50 lb.
3″ by 3″	1.40	FISP BLH-84	¼-inch	Wading Rod	
4″ by 8″	1.40	Elwha	¼-inch	Wading Rod/Cable	10-150 lb.
6″ by 6″	3.22	Helley-Smith	¼-inch	Cable	150-200 lb.
6″ by 12″	1.40	Hubbell #5	¼-inch	Cable	150-200 lb.
6″ by 12″	1.40	Toutle River Type 2	¼-inch	Cable	100-200 lb.

Single equal-width-increment bedload-sampling method



- Sampling time: Sample times normally range from 30 to 60 seconds.
- Number of verticals: approximately 20 across the width of the channel x 2 passes
- Tetherlines commonly used to keep the sampler stable

Edwards and Glysson, 1999

Sample processing:

- Particle-size analysis usually done on both suspended and bedload samples. Usually a sand/fine split or a full analysis of clay, silt, and sand fractions.
- Sample compositing:
  - Only samples collected with the same sampling times <u>and</u> width increments can be combined.
  - Recommend not combining until site-specific cross-sectional variations are known.

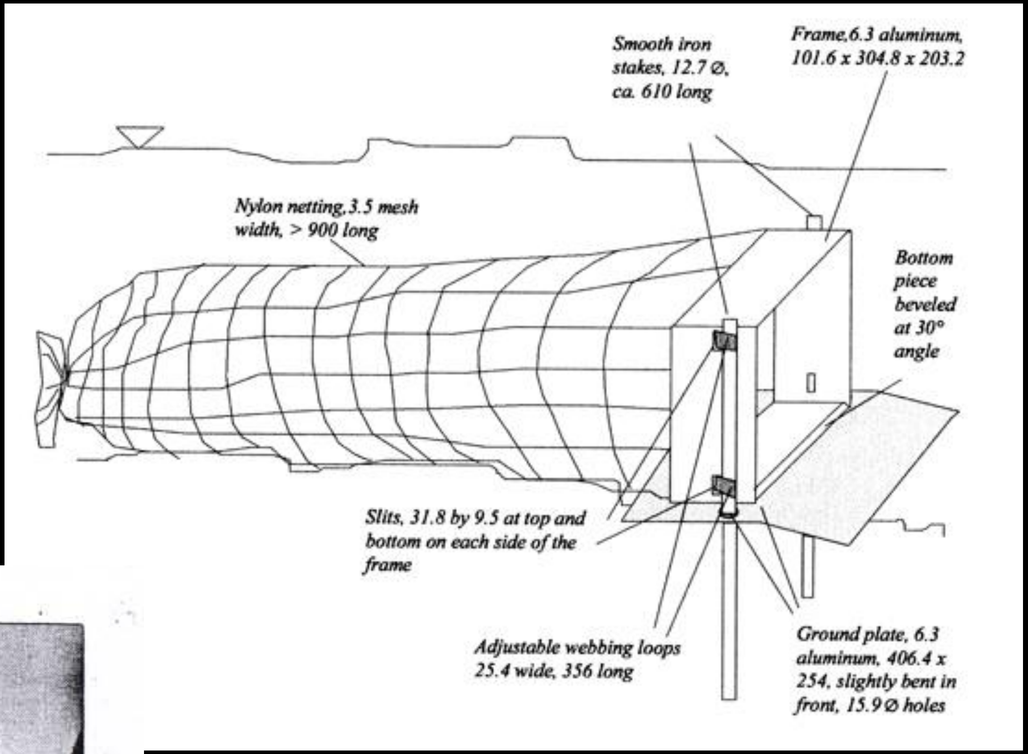
USGS

Bedload characterization—not only amount but size, origin can be important

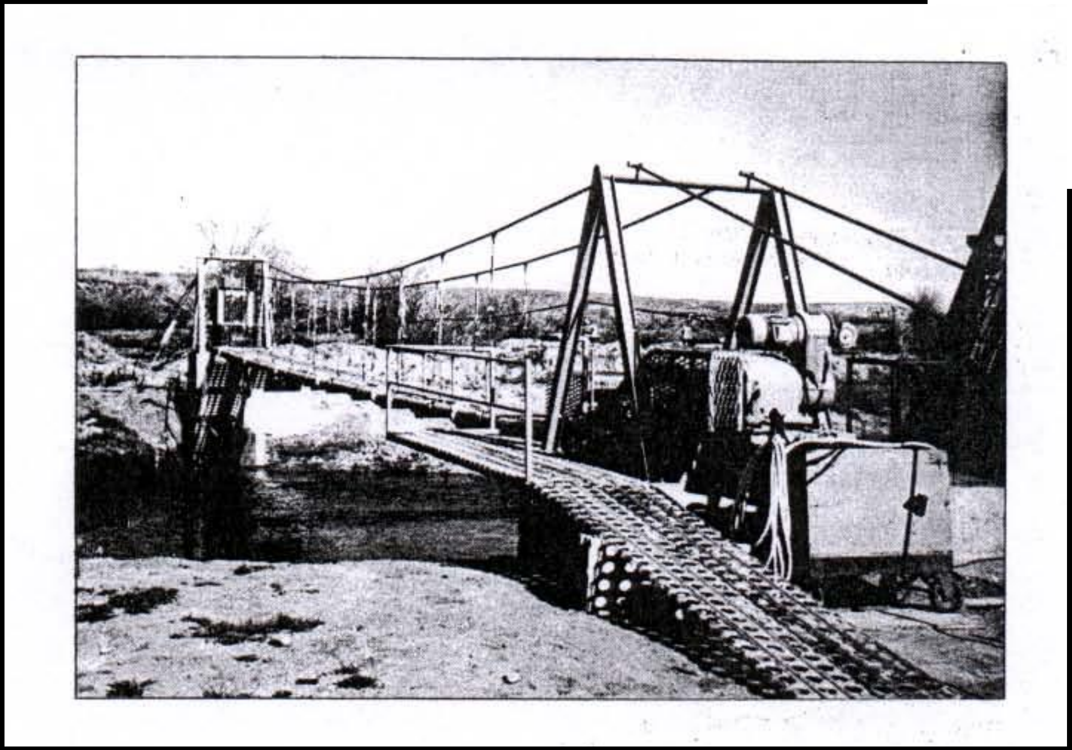
Photos Faith Fitzpatrick, Stillwell Creek, 2008

Bedload traps

- Collects everything that passes
- Hard not to have them overfill
- Locate in tandem
- Usually wadeable gravel bed



USFS Bunte's portable bedload trap



Leopold and Emmett's (1982)
bedload trap and conveyor on the East Fork
River for continuous bedload-transport rate

Particle tracking

Painted yellow rocks (also magnetic PIT sometimes used) and tracked downstream using a magnetic susceptibility probe

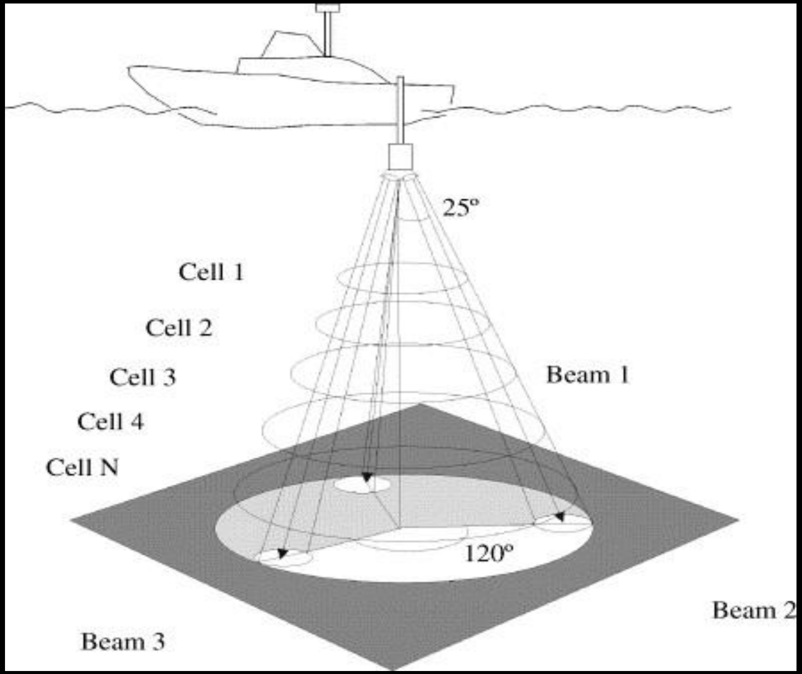
photo source T. Scott (FILTER) http://www.filter.ac.uk/database/getinsight.php?id=48&seq=13

Bedload surrogates

- In research stage
- Bed velocity
- Acoustic/impact
- Others?

Photo: Eric Dantoin, 2009

An acoustic Doppler current profiler (ADCP) measures three-dimensional velocity profiles within the water column using the Doppler shift principle, while the bottom tracking function and acoustic backscatter can be used to measure bed load velocity and estimate suspended sediment concentration.



(Gellis, 2007)

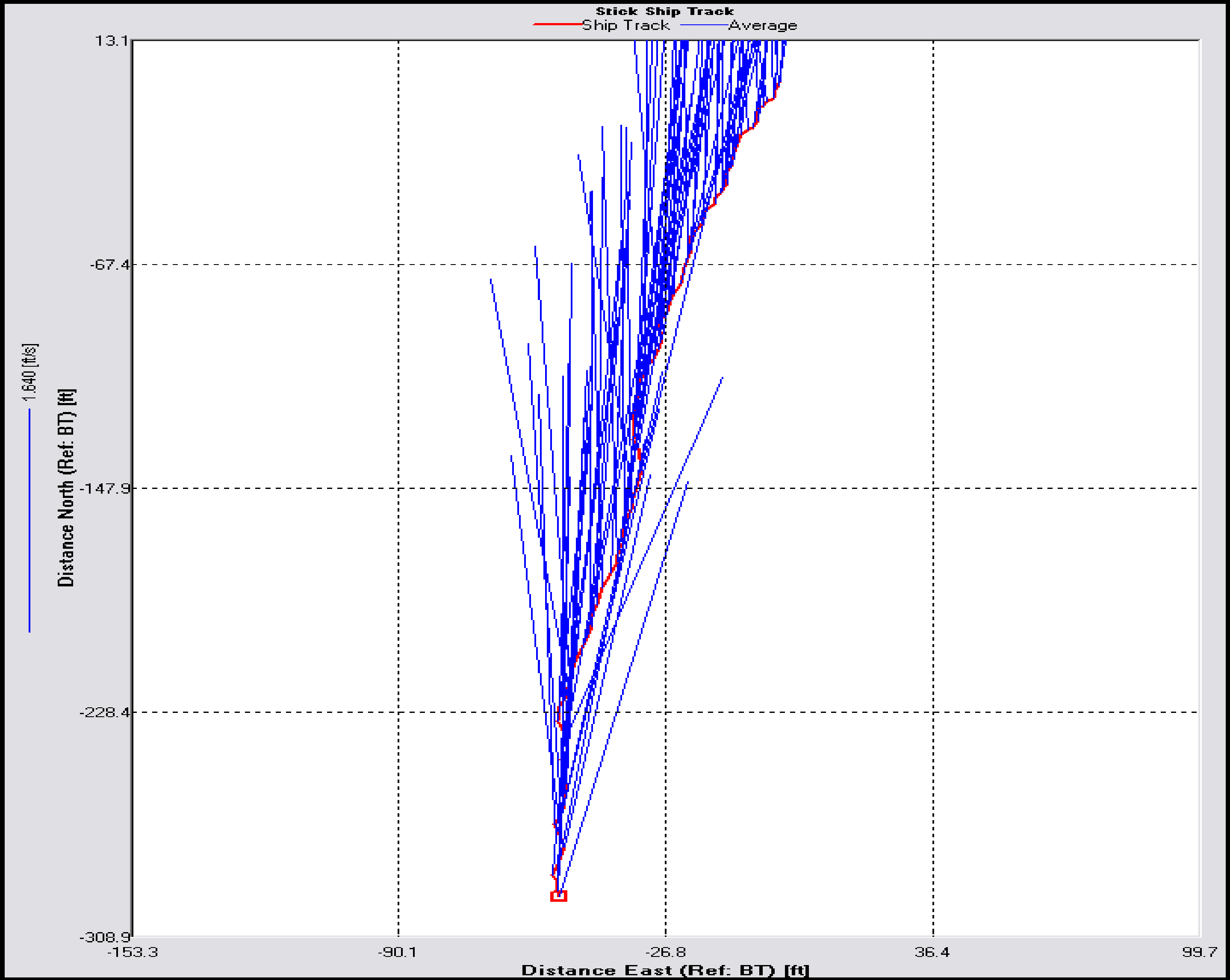
BEDLOAD SURROGATE

In cases where the bed is moving, the bottom tracking Doppler shift is a function of both the velocity of the boat and the moving bed.

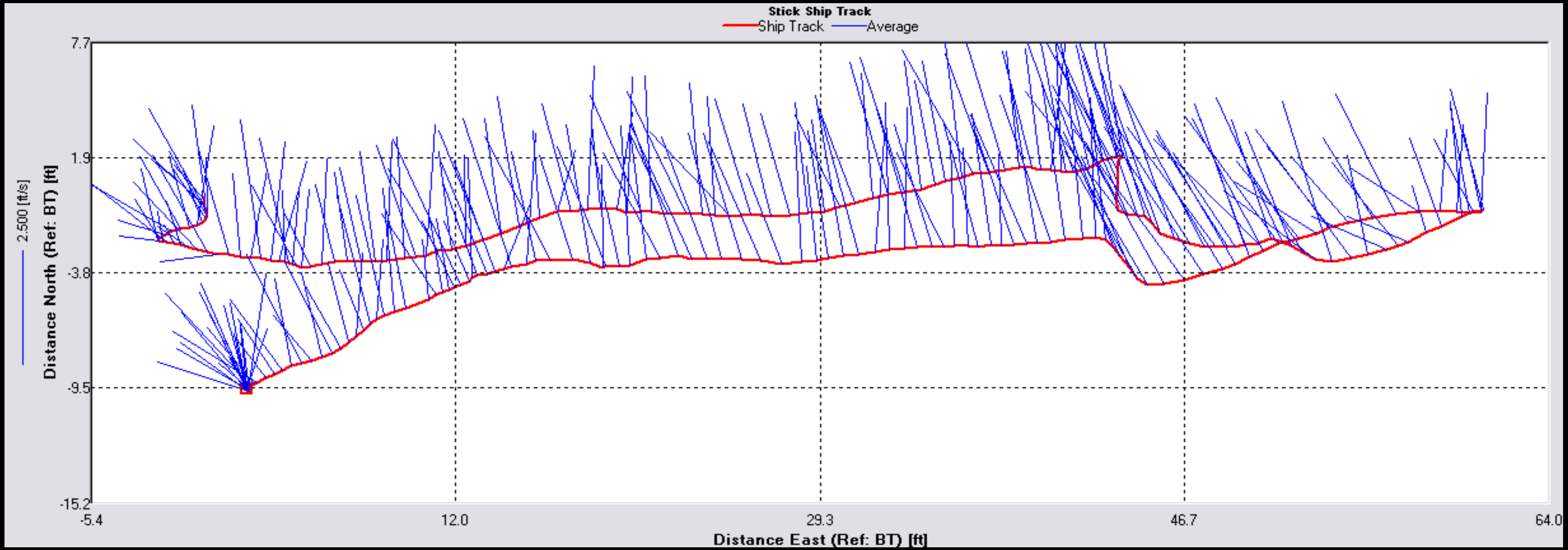
The ADCP bottom-track provides a direct estimate of bed load velocity but not of bed load flux.

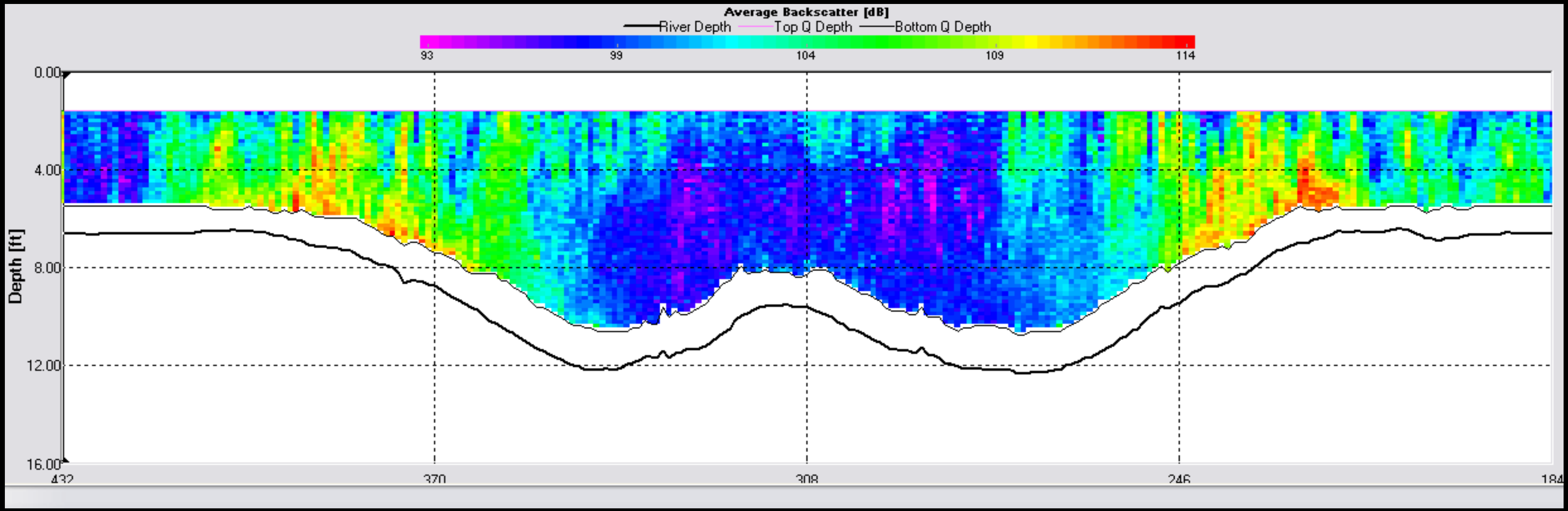
(Gellis, 2007)

Nemadji River nr South Superior, WI Stationary Moving Bed Test

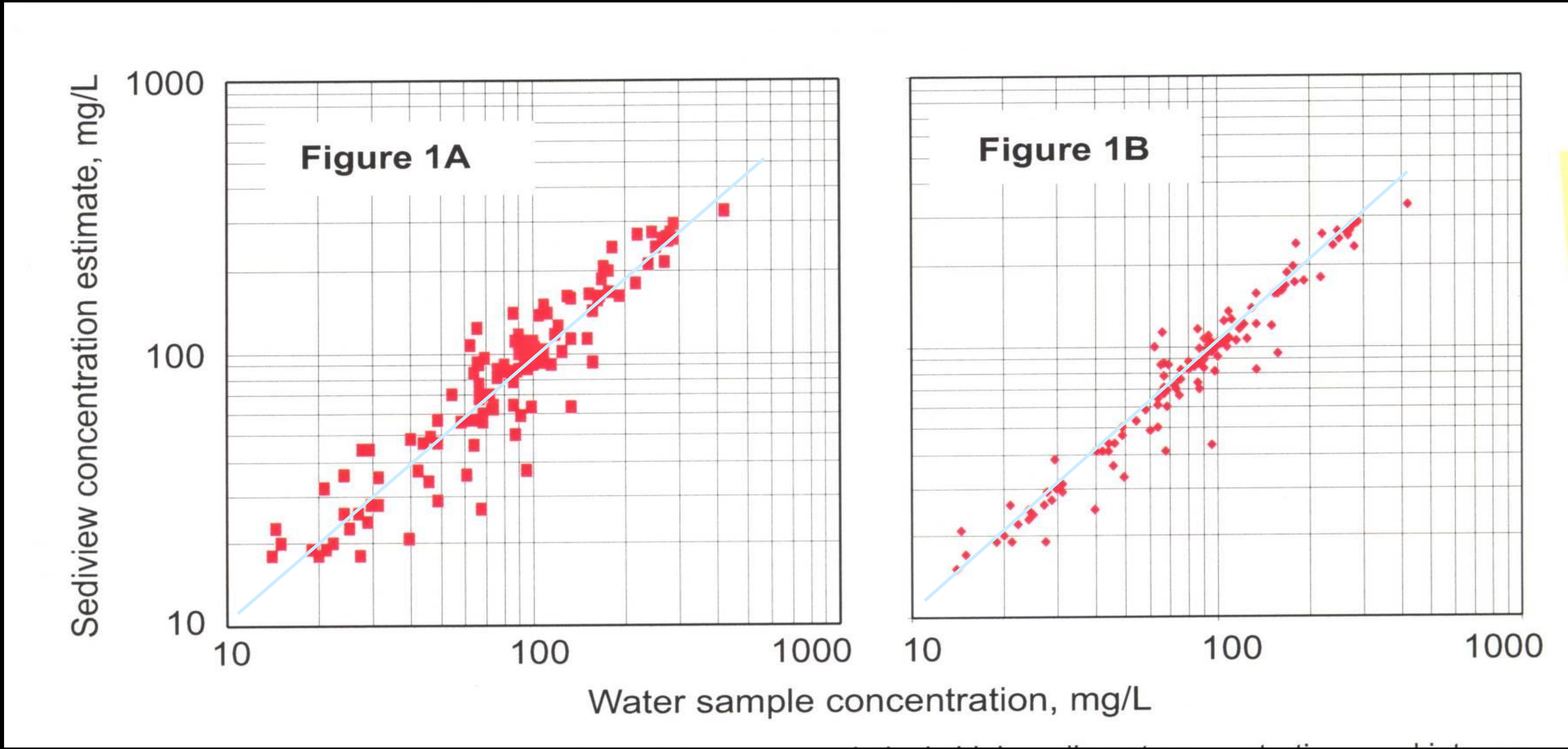


Nemadji River nr South Superior, WI Stationary Moving Bed Test





Suspended-Sediment Concentration by Acoustic Doppler Current Profiler



From printed literature, Dredging Research, LTD, UK

(Gellis, 2007)

Key USGS References:

A GUIDE TO THE PROPER SELECTION OF FEDERALLY APPROVED SEDIMENT AND WATER QUALITY SAMPLERS U.S. Geological Survey, Scientific Investigations Report 2005-1087, By Broderick Davis and FISP http://pubs.usgs.gov/of/2005/1087/pdf/OFR_2005-1087.pdf

FLUVIAL SEDIMENT CONCEPTS U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter C1 By Harold P. Guy http://pubs.usgs.gov/twri/twri3-c1/

FIELD METHODS FOR MEASUREMENT OF FLUVIAL SEDIMENT U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter C2 By Thomas K. Edwards and G. Douglas Glysson http://pubs.usgs.gov/twri/twri3-c2/

COMPUTATION OF FLUVIAL-SEDIMENT DISCHARGE U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter C3 By George Porterfield http://pubs.usgs.gov/twri/twri3-c3/

INTRODUCTION TO SUSPENDED-SEDIMENT SAMPLING U.S. Geological Survey, Scientific Investigations Report 2005-5077 By K.M. Nolan, J.R. Gray, and G.D. Glysson http://pubs.usgs.gov/sir/2005/5077/

Sediment Sampling in an Urban Environment

Photos: Bill Selbig

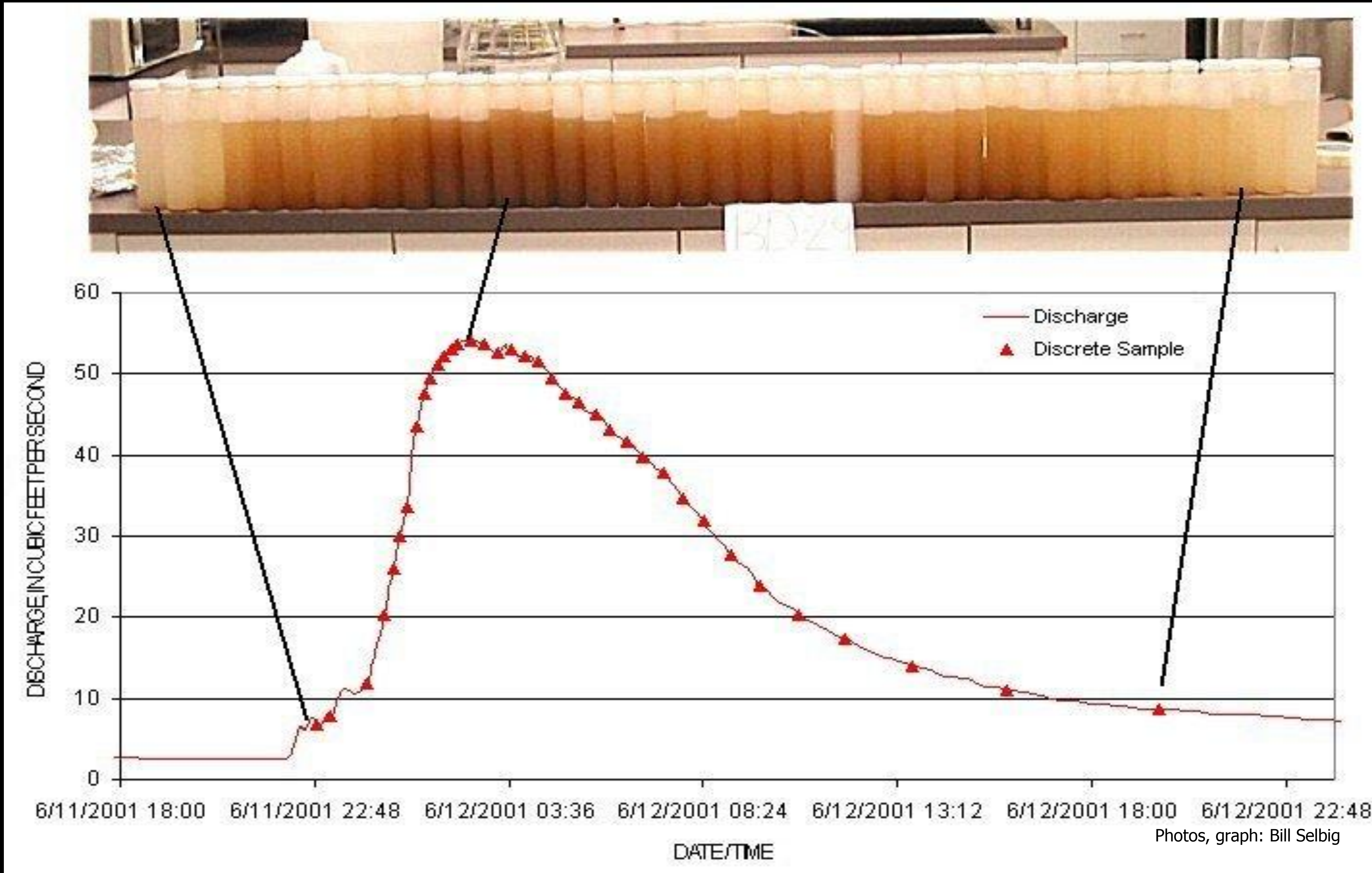
Photos: Bill Selbig

Sample Collection Challenges in an Urban Environment

- Small intake orifice in large pipe
- Difficult to achieve proper mixing
- Range of flows limits location of sampler intake
- Debris often inhibits good sample collection
- Concentrations biased towards bottom of water column

Photos: Bill Selbig

Automation is Important when Sampling an Urban System



Photos, graph: Bill Selbig

Identifying a Problem…

- Autosamplers frequently collect coarse particles
- Transferring these particles from sample jar to splitting device is difficult
- Are these particles an accurate representation of the average concentration?
- Are sediment concentrations biased based on sample intake location?

Photo: Bill Selbig

Total Storm Load = Suspended + Bedload

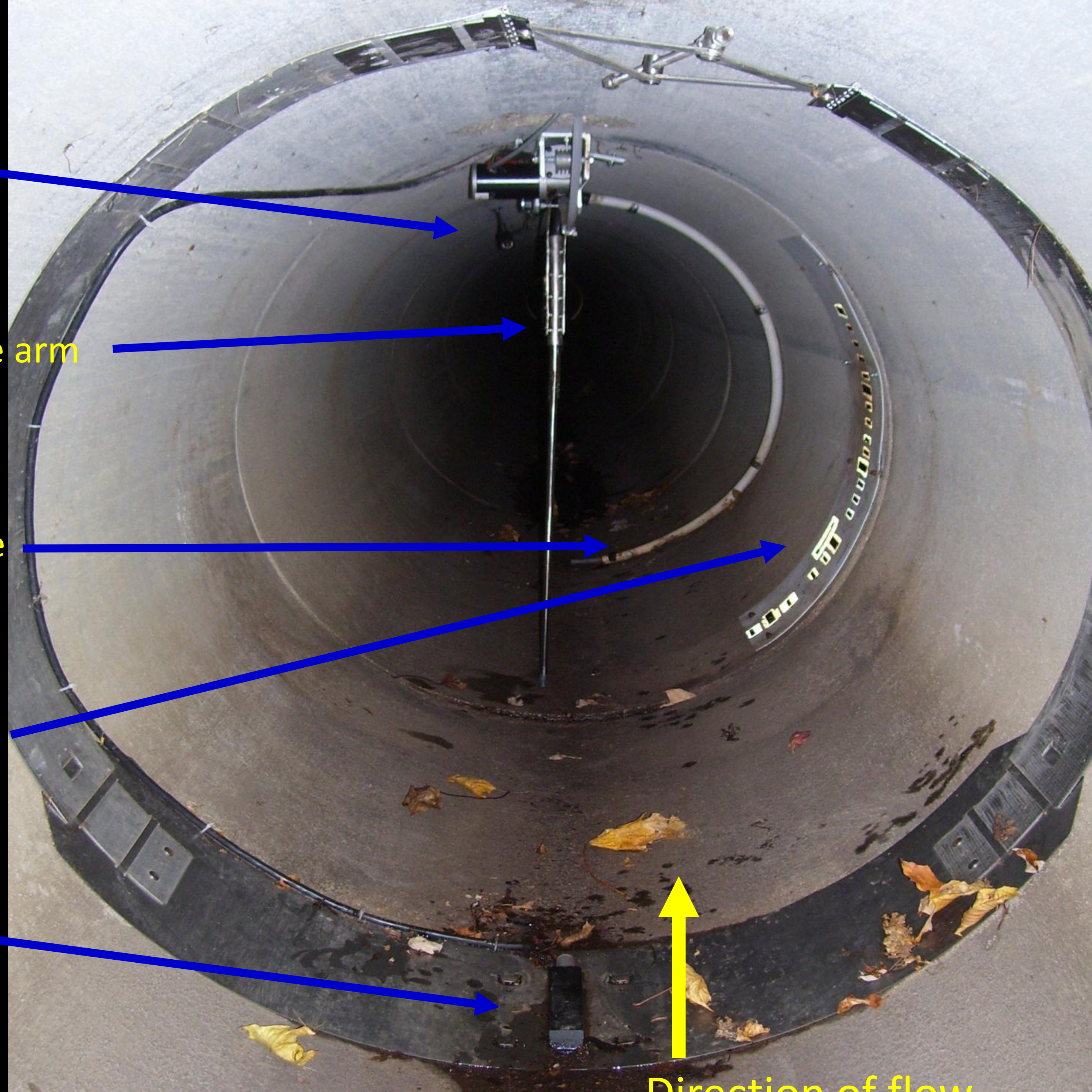
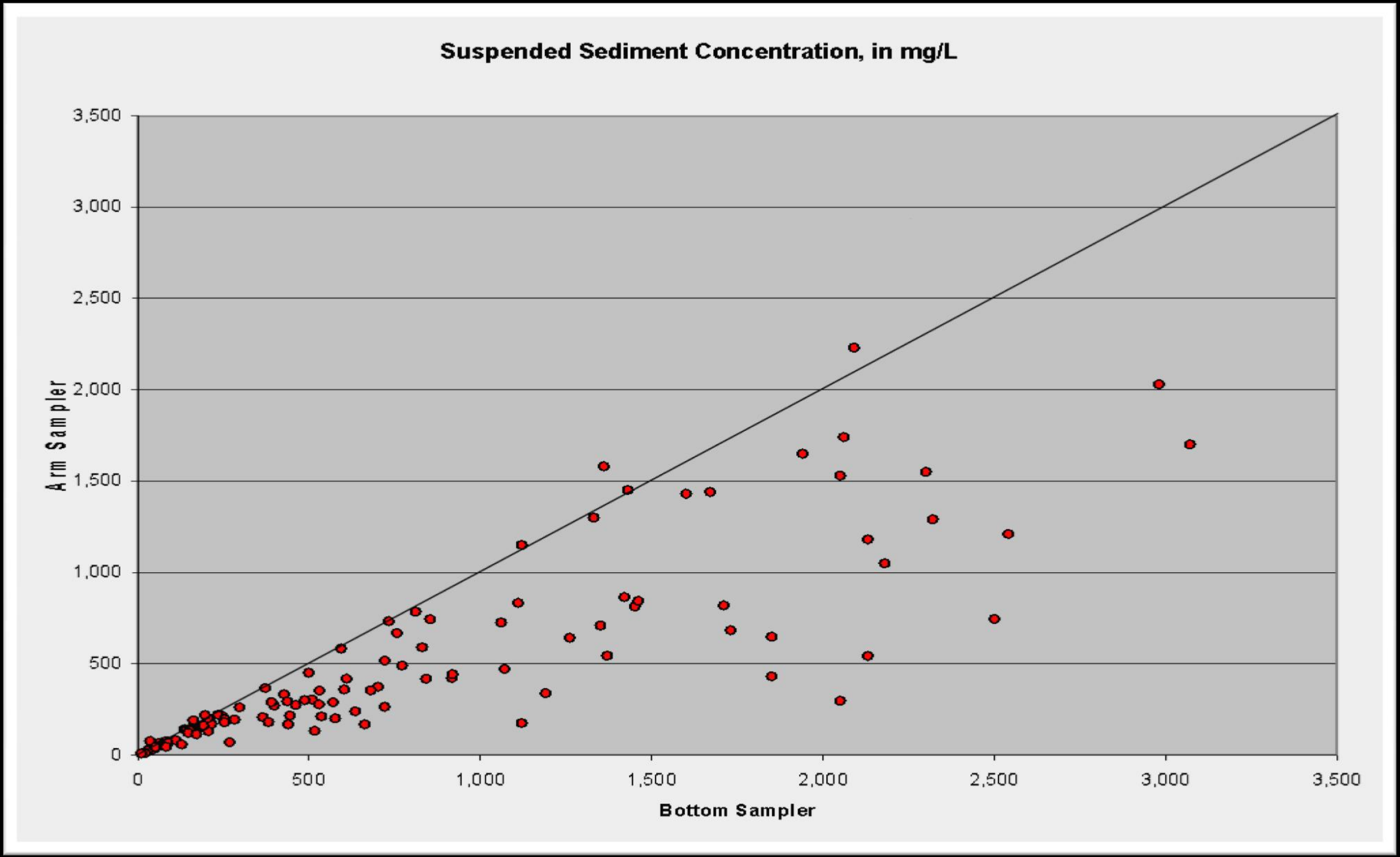
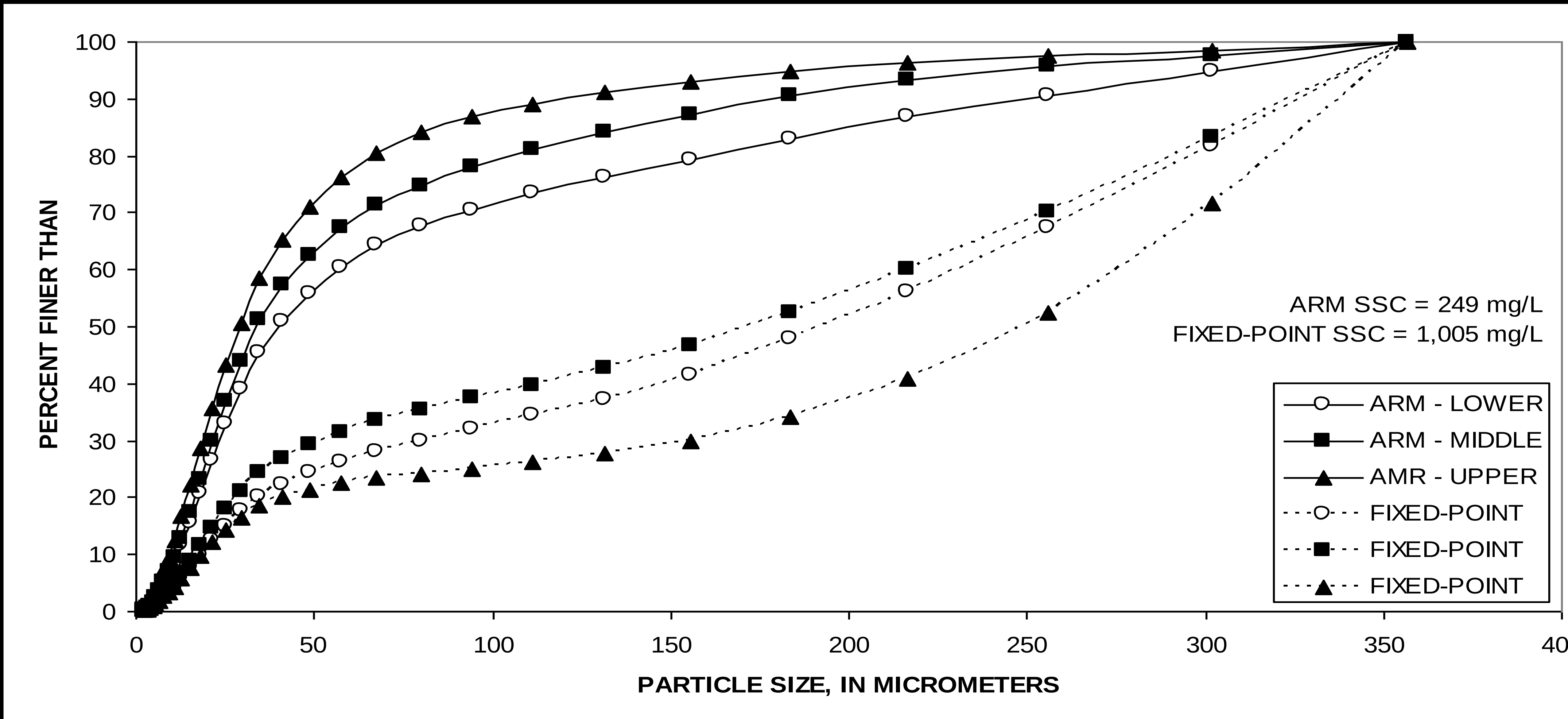


Photo: Bill Selbig

Concentration of Solids Can be Very Different Depending on Where You Take a Sample (Selbig, 2010, unpublished)



Grain Size Decreases With Increasing Depth



Unpublished data Bill Selbig, 2010

Measuring Storm Sewer Coarse Particle Transport (Bedload)

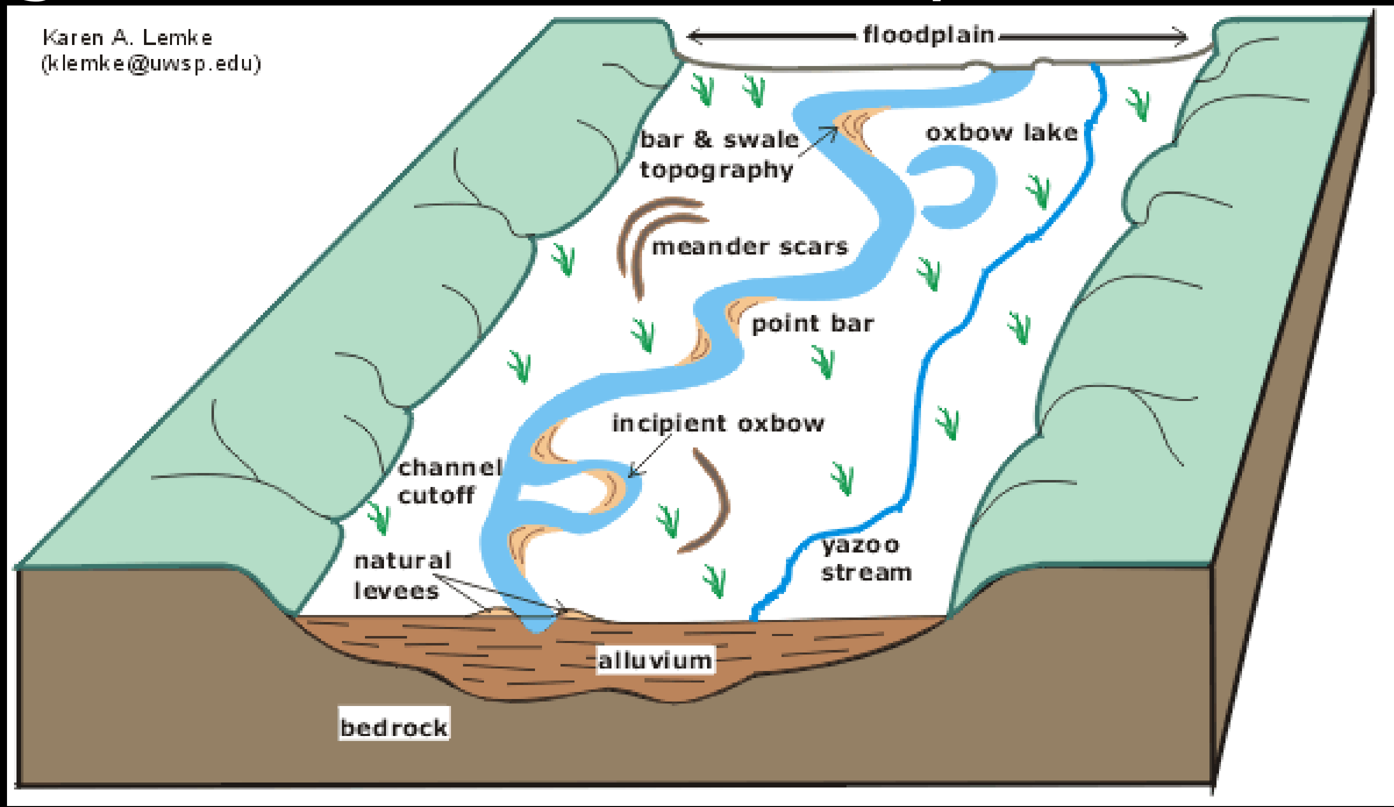
Photos: Bill Selbig

Consecutive Placement of Bedload Samplers in Downstream Array

Photos: Bill Selbig

Monitoring depositional features

- Channel bed sediment, depositional bars, floodplain alluvium and related landforms
- longer time scales than suspended/bedload



Channel cross sections

- channel morphology
- Planform (meandering)
- lateral adjustments
- vertical adjustments – deposition/erosion
- repeated
  - if measured 2-3 times per year can measure movement of temporarily stored sediment
- 2-3 channel widths apart, depending on goals
- extend upstream and downstream of rehabilitation

Pebble counts

- Many different techniques
- Design depends on goals
- Resampling frequency varies depending on goals
- Choose the best setup and technique to meet monitoring goals
- Incorporate fine sediment deposition into counts
- Use sand card for fines

Photo: Faith Fitzpatrick

Example pebble count

WISCONSIN REGIONAL BANKFULL CURVES FIELD SHEET

Developed by Marie Peppler (USGS), 2007

SECTION 4 - Pebble Counts

RIVER KITTESON VA. STATION ID DATE 10/19/2008

LOCATION TRUMAN RD. / ABOVE CTY. RD. H USGS GUAGE (ON BACK) TIME 9:10 AM - 1:20 PM

FIELD CREW FAITH FITZPATRICK, RYAN KURTZ DNR HABITAT SITE # 19

WEATHER Clear → Partly Coudy Cloudy Rain Snow Windy Breezy Temperature:

RIVER STAGE Stable, normal Peak Falling Rising Stable, low Stable, high Not Determined

PROTOCOL SUMMARY:

Size in mm will be recorded for 100 pebbles chosen at random from the channel bed from 10 transects

If the sample is covered in an organic fluff layer, MARK sample in box.

Sand or finer particles will be hand textured with the aid of a sand guage:

For <2 mm, record as follows:

VCS - very coarse sand	FS - fine sand	CL - clay
CS - coarse sand	VFS - very fine sand	OR - organic detritus
MS - medium sand	SI - silt	M - MACROPHYTES

If channel bed is more than 50% sand, see protocol for QA sampling method.

If channel bed is 100% sand, see protocol for sampling method.

PC1 - PEBBLE COUNT - Note location on Reach Map

RIFFLE at Transect Number _______

measurements in mm

ON BOTTOM GRID

FS_{80}	FS^{M}_{0}	FS^{M}_{0}	150^{M}_{40}	400^{M}_{25}	35^{M}_{80}	25_{0}	210_{0}	110_{0}	200_{0}	10
	CS_{10}	11_{0}	FS^{M}_{0}	MS^{M}_{0}	150^{M}_{0}	400^{M}_{0}	65^{M}_{0}	20^{M}_{40}	510_{0}	9
9_{0}	VCS^{M}_{0}	FS^{M}_{0}	95^{M}_{0}	42^{M}_{0}	14^{M}_{0}	15_{0}	130_{0}	350_{0}		8
		MS_{0}	3_{0}	MS^{M}_{0}	MS^{M}_{0}	CS^{M}_{0}	20^{M}_{40}	150^{M}_{0}	32_{0}	7
15_{0}	110_{0}	FS^{M}_{0}	50^{M}_{20}	25^{M}_{10}	40_{0}	250_{0}				6
			FS^{M}_{0}	60^{M}_{0}	20^{M}_{0}	60^{M}_{0}	40^{M}_{0}	80^{M}_{0}	160_{0}	5
MS^{M}_{0}	FS^{M}_{0}	160^{M}_{0}	VFS^{M}_{0}	16^{M}_{0}	300_{0}	70_{0}	250_{0}			4
		SI_{120}	MS_{0}	MS^{M}_{0}	MS^{M}_{0}	VFS^{M}_{0}	FS^{M}_{0}	125_{0}	25_{0}	3
FS_{20}	40_{0}	80_{0}	75^{M}_{0}	CS_{0}	FS^{M}_{0}	25_{0}	68_{0}			2
SI_{50}	SI_{0}	FS_{0}	10_{0}	70_{0}	MS_{0}	15_{0}	40_{0}	15_{0}	CS_{30}	1

Notes: SOFT SEDIMENT PRESENT

M → MACROPHYTES

CS_{20}

DEPTH OF FLUFF (SOFT) SEDIMENT

BOTTOM SUBSTRATE (WIDTH)(PEBBLE SIZE)

DOWNSTREAM START

PC2 - PEBBLE COUNT - Note location on Reach Map

RIFFLE at Transect Number _______

measurements in mm

Notes: BASE FLOW IS HIGH STREAM SEEMS STABLE

FS_{70}	10_{0}	25^{M}_{170}	40^{M}_{140}	120^{M}_{20}	40^{M}_{60}	25^{M}_{0}	70_{0}	62_{0}	85_{0}	11
FS_{100}	34_{0}	45^{M}_{130}	18^{M}_{60}	115^{M}_{60}	15_{0}	55_{0}	35_{0}	44_{0}		12 most u/s transect

Fitzpatrick, unpublished, 2009

Mapping fine sediment deposition and bar formation

- Measure area in field or on aerial photos
- Distinguish type of bars – coarse/fine sediment
- Position and process of formation
- Use pebble count for particle size

Mixed Load Streams

Photo: Faith Fitzpatrick, Bad River, 2009

Suspended load streams

Photo: Mark Godfrey,The Nature Conservancy, 2009

- Measure area and depth to calculate volume
- Convert volume to weight by sampling for dry bulk density
- Field intensive but data rich
- Fine sediment depth = "muck you can step through"
- Conduct measurements over time

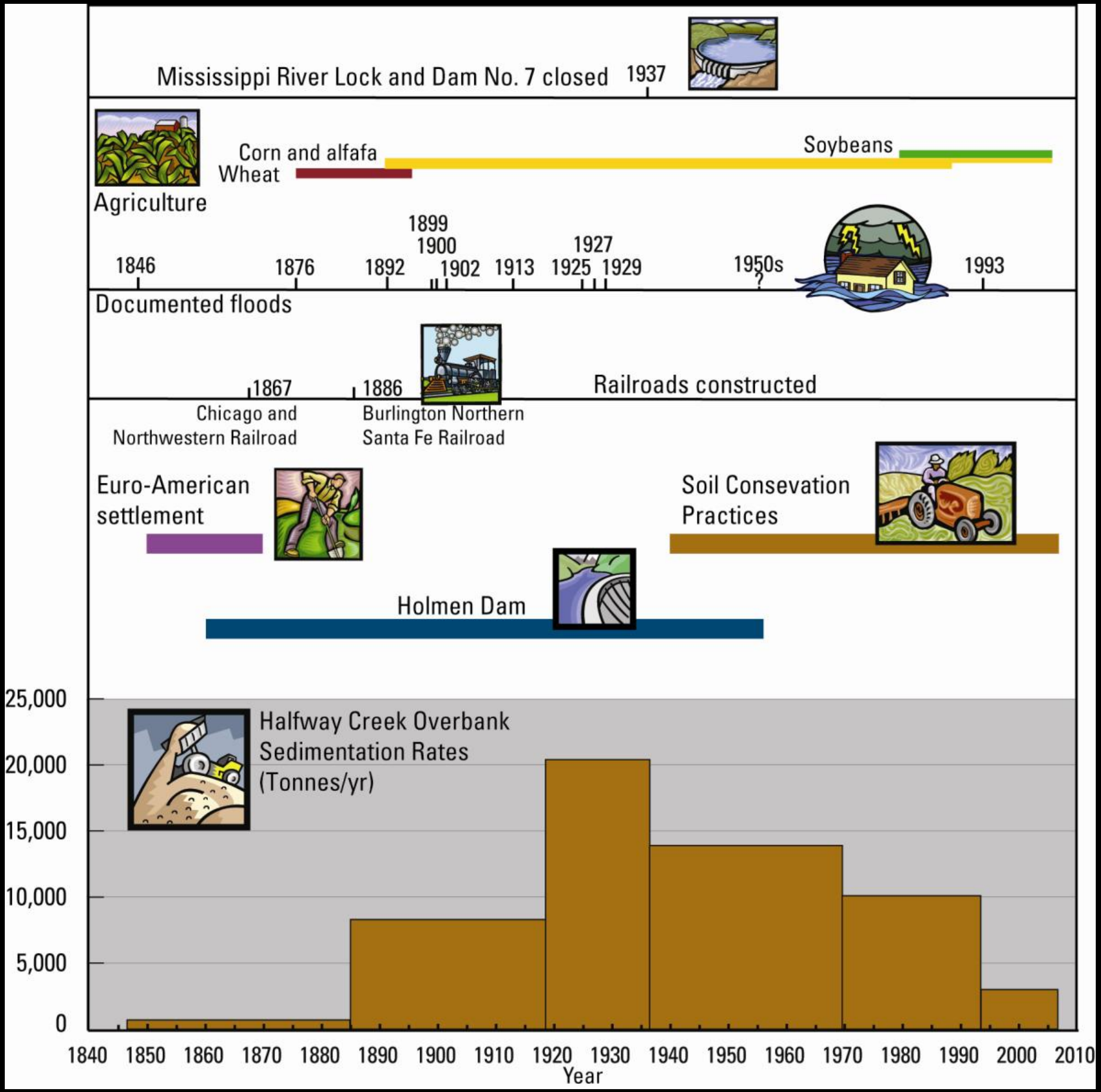
Floodplain deposition

- Reconstruct long-term sediment loadings based on overbank sedimentation rates
- Combines channel position changes, radiometric dating, identification of buried soils

photo by JC Knox

Driftless Area Wisconsin -- Overbank Sedimentation Gives Clues to Past Changes in Sediment Loading

Modern sediment loads 2-4x higher than natural loads but pre-conservation loads were ~30x higher
(Halfway Creek; Fitzpatrick and Knox, 2009)



Sediment summary

- Lots of tools at various scales
- GET REAL DATA!
- Use a variety of techniques over different spatial and temporal scales
- For suspended sediment loads – looking for 100-120 concentrations over a year from automated sampler + cross section samples – very intensive
- If using turbidity as a surrogate, need to calibrate to suspended sediment concentration
- Surrogates – usually need site-specific calibration data